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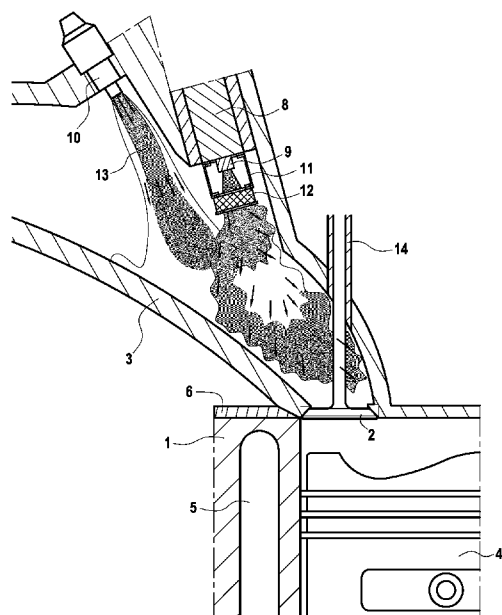


FIG.1

(57) Abstract: Provided is a fuel injected combustion engine (1) comprising an intake port (3) in controllable fluid communication with a cylinder of the fuel injected combustion engine (1), fuel delivery means in fluid communication with the intake port (3) and positioned to facilitate provision of fuel into the intake port (3), said fuel delivery means comprising a dual port fuel injection (PFI) structure having a first and a second injector (8, 10), wherein the first injector (8) comprises a nozzle (9) and a three-dimensional porous medium (12) positioned between the cylinder and the nozzle (9), and configured to disperse fuel provided by the nozzle (9) via a plurality of pores in the porous medium (12).



## **SYSTEM AND METHOD FOR ENHANCED AIR/FUEL HOMOGENIZATION**

### FIELD OF THE DISCLOSURE

5 [001] The present disclosure is related to reducing fuel-film formed on the surface of intake port or valve during cold start and/or warm-up phase of an internal combustion engine, and more particularly to improved homogenization of an air/fuel mixture prior to combustion in an internal combustion engine. The proposed system is suitable for full engine map operation during driving cycles  
10 and will further reduce unburned hydrocarbons and CO emissions in the engine's exhaust.

### BACKGROUND OF THE DISCLOSURE

15 [002] In port fuel injected (PFI) engines fuel delivery is typically performed outside the cylinder in an attempt to obtain a fairly homogeneous charge, which is desired for improving full combustion. In these engines the fuel spray is injected from a fuel injector towards an inner wall of an inlet duct of the cylinder head, which may result in fuel accumulation on the inner wall. This  
20 effect may be particularly prevalent due to condensation where the engine is not yet warmed to operating temperature.

[003] Fuel mixture preparation may occur by fuel evaporation from the fuel accumulated on the inner wall, and suspended droplets that are introduced during each injection cycle.

25 [004] One of the challenges facing PFI engines is the completion of mixture preparation at cold start and/or warm-up phase when the temperatures of intake duct walls and inlet valves are low. During these "cold start" periods, available time for complete fuel evaporation is short and the level of turbulence in the flow is low. These problems may result in imprecise fuel metering due to  
30 reduction of amount of fuel induced in the cylinder compared to that of injected; incomplete combustion and high peak of unburned hydrocarbons and carbon monoxide due to inlet port and valve surface wetting; and incomplete in-cylinder droplet evaporation, among others.

[005] DE 2306362 discloses a two-dimensional mesh or net layer  
35 positioned downstream (i.e., in front of) of a fuel injector in the intake port.

The mesh is intended to facilitate cold start conditions and engine operation by improving initial fuel vaporization and reducing wall film formation in the intake port and on the valve surfaces. However, this net has a limited number of pores which are incapable of dispersing the fuel in a wide pattern within intake  
5 port. Therefore, in spite of some level of additional air/fuel mixture homogenization the degree of homogenization may not be sufficiently enhanced to achieve full combustion and eliminate the drawbacks discussed above.

[006] In order to address these disadvantages, WO2019166094 A1  
10 discloses a PFI injector comprising a heated porous material placed in the flow of injected fuel. The function of the porous media (PM) is to facilitate cold start conditions and engine operation by improving initial fuel vaporization and reducing wall film formation in the intake port and on the valve surfaces. In the proposed method in WO2019166094 A1, one or two 3D discs consisting of a  
15 porous media are considered in front of the injector to improve fuel distribution and evaporation. Due to high number of pores the PM spreads the fuel wide enough to create a homogenous mixture and reduce fuel interaction with the surface of intake port/ valve and therefore reduce the possibility of spray wall interaction. However, at high load condition there would be a chance of fuel  
20 droplet accumulation inside the media due to high amount of fuel injection which can increase the amount of UHC (unburnt hydro carbon), CO and soot in the exhaust.

#### SUMMARY OF THE DISCLOSURE

25 [007] The present inventors have recognized that in WO2019166094 A1 spray impingement on a highly porous structure results in quick spatial distribution of the spray across the injection direction and formation of multi-jet splitting effect. Therefore improvements in air/fuel homogenization are  
30 desirable, for example, to obtain fast fuel evaporation when the media is heated and to reduce spray penetration and therefor spray wall interaction especially at cold start condition.

[008] According to embodiments of the present disclosure, a fuel injected combustion engine is provided. The engine comprises an intake port in  
35 controllable fluid communication with a cylinder of the fuel injected combustion

engine, fuel delivery means in fluid communication with the intake port and positioned to facilitate provision of fuel into the intake port, said fuel delivery means comprising a dual port fuel injection (PFI) structure having a first and a second injector, wherein the first injector comprises a nozzle and a three-dimensional porous medium positioned between the cylinder and the nozzle, and the first injector being configured to disperse fuel provided by the nozzle via a plurality of pores in the porous medium.

[009] Hence, a novel design with a dual port fuel injection (PFI) structure is proposed which utilizes two injectors: an injector with a three dimensional (3D) porous medium (PM) structure, e.g. an assisted reticulated PM, and a conventional port fuel injector for supporting warm-up operation of the engine.

[0010] By providing such a system, unique properties of porous structures e.g. large surface area and high heat capacity may be utilized to increase the chance of fast fuel evaporation when the media is heated and reduce spray penetration and therefore spray wall interaction especially at cold start condition. A strong heat transfer from hot PM-surface to liquid fuel, when the medium is heated, permits fast and complete fuel vaporization. This may in turn make the mixture homogenization in the intake port easier and faster.

[0011] In particular, the homogenization of an air/fuel mixture may be improved due to dispersion of the fuel through a three-dimensional porous medium. In causing an "injected" fuel spray to pass through a three-dimensional porous medium, a fuel rich "core" of the injected spray may be more thoroughly dispersed upon traversing a dimension called thickness of the medium, and thereby, more readily combined with intake air.

[0012] The term "three-dimensional," as used herein, shall be understood to mean a medium that, in addition to presenting a surface area (that is substantially perpendicular to a mean direction of the fuel spray), has an observable third dimension, i.e. the thickness, for example greater than 2 mm, and more specifically, between e.g. 5 and 10mm.

[0013] Accordingly, fuel-wall wetting can be reduced on the surface of the intake port and an intake valve during cold start and/or warm-up phase of an gasoline engine. The proposed design is thus suitable for full engine map operation during driving cycles and will further reduce unburned hydrocarbons and CO emissions in the engine's exhaust.

[0014] Only one porous medium (instead of e.g. two as proposed by WO2019166094A1) may be used in the first injector for the sake of simplicity. However, also a plurality of porous media may be used, e.g. two or three.

5 [0015] Only the first of the two injectors may comprise a three-dimensional porous medium positioned between the cylinder and the nozzle. In other words, the second injector may comprise a nozzle configured to directly inject the fluid into the intake port without being dispersed by a porous medium.

10 [0016] The second injector may be arranged at the intake port upstream of the first injector along the direction of the intake flow.

[0017] The second injector may be more inclined toward the downstream side of the intake port than the first injector.

[0018] Accordingly, in the present design, beside the PM assisted injector, the second injector may also be considered upstream of the intake port. The  
15 second injector may be considered here to achieve fast response to high load demand in which higher amount of fuel is injected and engine operating condition is warmed-up enough for fast evaporation of fuel.

[0019] The narrow angle of spray of the second injector may be advantageous to target the spray closer to the intake valve for shortening the  
20 response time of the engine at high load demand condition.

[0020] The second injector may be configured to only operate when a predefined engine warmup condition is satisfied, in particular when the temperature of an engine coolant reaches a predetermined temperature.

[0021] Hence, to avoid accumulation of fuel inside the PM due to high  
25 frequency of injection and higher amount of injected fuel, the second injector may be operational only after warm-up condition when the engine coolant temperature reaches a steady state value (90-100°C degree).

[0022] The first injector may comprise a holder configured to hold the porous medium, wherein said holder protrudes into the intake port such that  
30 the porous medium is exposed to an air flow in the intake port.

[0023] Accordingly, the first injector may be arranged within a first injection location and may protrude from said injection location into the intake port, such that the holder and the porous medium are arranged within the intake port, and therefore are exposed to a flow of air in the intake port while the porous

medium is mechanically held by the holder in a fixed manner with respect to the first injector.

[0024] The present disclosure further relates to a fuel injected combustion engine, comprising an intake port in controllable fluid communication with a cylinder of the fuel injected combustion engine, and fuel delivery means in fluid communication with the intake port and positioned to facilitate provision of fuel into the intake port, said fuel delivery means comprising a port fuel injection (PFI) structure having at least one injector.

The at least one injector comprises a nozzle and a three-dimensional porous medium positioned between the cylinder and the nozzle, the at least one injector being configured to disperse fuel provided by the nozzle via a plurality of pores in the porous medium, and a holder configured to hold the porous medium, wherein said holder protrudes into the intake port such that the porous medium is exposed to an air flow in the intake port.

[0025] Accordingly, by providing such a holder, the cylindrical porous medium can be exposed to the flow of intake air and can be flushed regularly during each intake process while being supported by the holder.

[0026] The three dimensional porous medium may have a pore density between 10 and 20 PPI (pores per inch), and preferably a porosity greater than 80 percent.

The three dimensional porous medium may have a thermal conductivity between 80 and 160W/m.K.

[0027] The holder of the at least one injector or the first injector may have a frame structure which encases or accommodates the porous medium and has a plurality of openings such that the encased or accommodated porous medium is exposed to an air flow in the intake port through the openings of the frame.

[0028] The holder may be configured to maintain the porous medium at a predetermined distance relative to an injector nozzle of the first injector or the at least one injector. More particularly, the holder may be configured to adjust the distance between the porous medium and the injector nozzle, e.g. through adjusting members.

[0029] The engine and in particular the holder may comprise a heater configured to increase a temperature of the three-dimensional porous medium.

[0030] Heating of the three-dimensional porous medium may further improve evaporation of fuel and homogenization of the air/fuel mixture, thereby leading to improved combustion, especially at cold-start.

5 [0031] The heater may comprise a glow plug inserted at least partially into the three-dimensional porous medium.

[0032] The heater and/or the holder may comprise an electric heater in contact with at least a portion of an outer surface of the three-dimensional porous medium.

10 [0033] The three-dimensional porous medium may comprise a porous ceramic foam, e.g. silicon carbide (SiC).

[0034] The three-dimensional porous medium may comprise a porous metallic foam, e.g. Cu and/or Ni-Cr-Al.

[0035] The present disclosure further relates to a vehicle comprising a fuel injected combustion engine as described above.

15 [0036] The present disclosure further relates to a method for homogenizing an air/fuel mixture of a fuel injected combustion engine, the method comprising:

20         injecting fuel provided by a first injector through a three-dimensional porous medium into an intake port of the engine which disperses the injected fuel, and

              injecting fuel provided by a second injector directly into the intake port without being dispersed by a porous medium.

[0037] The first injector may inject fuel during a cold-start of the engine, e.g. only during a cold-start of the engine.

25 [0038] The second injector may only inject fuel when a predefined engine warm-up condition is satisfied, e.g. when the temperature of an engine coolant reaches a predetermined temperature.

[0039] The method may further comprise heating the three-dimensional porous medium during a cold-start of the engine.

30 [0040] It is intended that combinations of the above-described elements and those within the specification may be made, except where otherwise contradictory.

[0041] The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate embodiments of the disclosure and together with the description, and serve to explain the principles thereof.

35

## BRIEF DESCRIPTION OF THE DRAWINGS

[0042] Figure 1 shows a cross section of one cylinder of an exemplary porous material assisted dual port fuel injection (PFI) engine according to  
5 embodiments of the present disclosure;

[0043] Figure 2A shows an exploded view of the porous material and holder structure of Figure 1 according to embodiments of the present disclosure ;

[0044] Figure 2B shows a cross-sectional view showing the first injector of the PFI engine of Figure 1 equipped with the porous material and holder  
10 structure of Figure 2A according to embodiments of the present disclosure;

[0045] Figure 3 shows an exploded view and a side view of the porous material and a holder structure according to a variant embodiment.

## DESCRIPTION OF THE EMBODIMENTS

15

[0046] Reference will now be made in detail to exemplary embodiments of the disclosure, examples of which are illustrated in the accompanying drawings. Wherever possible, the same reference numbers will be used throughout the drawings to refer to the same or like parts.

20 [0047] Figure 1 shows a cross section of one cylinder of an exemplary porous material assisted dual port fuel injection (PFI) engine 1 according to embodiments of the present disclosure.

[0048] One of skill understands that while a single cylinder is shown and discussed for purposes of explanation, the porous material assisted PFI spark-  
25 ignition internal combustion engine may comprise as many cylinders as desired, each having a similar configuration to that described herein.

[0049] As shown in Figure 1, the PM-assisted PFI spark-ignition internal combustion engine 1 comprises an intake valve 2 at the downstream end of an intake port 3. Parts 4 and 5 show the piston and coolant jacket around a  
30 cylinder wall of the engine respectively. A cylinder head gasket 6 is provided on the top of the cylinder. Engine 1 includes an electrically controlled (e.g., electronically controlled via an ECU) gasoline fuel injector 8 (i.e. a first injector according to the disclosure) that injects fuel onto a cylindrical porous medium 12 positioned in front of the tip of the nozzle 9 (the nozzle protrudes from the  
35 injector body). Engine 1 may also include a second fuel injector 10 that is

adapted to inject fuel into the intake port 3 farther from the intake valve 2 than the first injector 8 as will be described subsequently. A valve guide 14 may be provided outside the intake port 3 to guide the valve 2.

[0050] The first fuel injector 8, being part of a fuel delivery means, may be  
5 affixed to the injection port (e.g. via fasteners) and configured to inject fuel into the cylinder formed in block 5 in which piston 4 reciprocates such that the air/fuel mixture may be subsequently ignited (e.g. via a spark) within the cylinder. General operation of a combustion engine is well understood by one of skill in the art and will not be discussed in detail herein.

10 [0051] The injection port which receives the first electronically controlled fuel injector 8 may be in fluid communication with intake port 3.

[0052] The first and second fuel injectors 8, 10 may be configured to inject any type of fuel suitable for combustion in the PFI combustion engine, e.g., gasoline, ethanol, methanol, etc. Particularly, the injectors may be configured  
15 to provide/inject fuel to the intake port and the provided/injected fuel may be entrained by an airflow carried by the intake port into the cylinder upon opening of valve 2 at a particular timing.

[0053] The three-dimensional porous medium 12 configured to disperse the fuel provided by fuel injector 8 is positioned between fuel injector 8 and the  
20 cylinder into which the -fuel-air mixture is to be injected.

[0054] The three-dimensional porous medium 12 comprises a porous material, i.e., a material comprising a plurality of pores permitting fluids to pass through from an impingement side of the medium to an exit side of the medium, by traversing various pores present within the porous medium 12.  
25 The three-dimensional porous medium may comprise, for example, a metallic or ceramic foam.

[0055] According to some embodiments, a porosity of the three-dimensional porous medium may be greater than 70 percent, greater than 80 percent, and in some embodiments, greater than 90 percent. In any case, the porosity of  
30 the three-dimensional porous medium is less than 100 percent.

[0056] The three-dimensional porous medium may be fabricated from a ceramic foam, for example, of high thermal conductivity, such as, for example, a silicon carbide (SiC) or Aluminum oxide (Al<sub>2</sub>O<sub>3</sub>). Alternatively, or in addition, the three-dimensional porous medium may be fabricated from a metallic foam,

such as, for example, copper (Cu) or Aluminum (Al) or nickel-chromium-aluminum (Ni-Cr-Al).

[0057] The distance between the tip of the first injector 8 (tip of the nozzle 9) and the PM surface (e.g. the PM front surface) may be adjusted to obtain  
5 optimized fuel dispersion within port volume and reduce fuel reflection from the medium surface.

[0058] The first injector 8 may comprise a holder 11 configured to hold the porous medium 12, wherein the holder protrudes into the intake port 3 such that the porous medium 12 is exposed to an air flow in the intake port, In other  
10 words, the first injector 8 is arranged within a first injection port and protrudes from said injection port into the intake port 3, such that the holder 11 and the porous medium 12 are arranged within the intake port as shown in Figure 1.

[0059] During engine operation (cold or warm) there is a chance of liquid fuel accumulation inside the porous structure due to repeated fuel injection  
15 onto the porous medium. Therefore the holder 11 with open area may hold the porous medium 12 while leaving enough exposure of the held porous structure to the outside intake air for complete flushing of the medium. This can remarkably reduce the chance of fuel build-up inside the medium, in particular when the PM is not yet fully warmed up. More particularly, the holder may  
20 comprise a frame structure that encases the porous medium 12 and that has several openings to the outside so as to allow outside air flow (airflow within the intake port 3) to enter the openings and the encased porous medium. Moreover, the possibility of removing the first injector 8 with the PM 12 and its holder 11 altogether provides easy maintenance of the system or when there is  
25 a need for replacement of the PM.

[0060] A heater (not represented in the drawings) may be accommodated around the PM 12 using the holder 11. The heater may increase the temperature of the PM before the start of the injection process, to a temperature which is required for evaporation of the fuel at cold start condition.  
30 The well distributed and evaporated fuel spray is entrained with the intake air flow within the intake port 3 and creates a homogenous combustible mixture which flows into the cylinder when intake valve 2 is open. Hence, the fuel supply is expected to become a well evaporated fuel cloud. This will significantly reduce the chance of wall film formation especially at cold start.  
35 After the resultant fuel-air mixture has been introduced into the cylinder and

intake valve 2 has been closed, the sufficiently homogenous charge is then ignited by a spark plug (not shown) to ensure complete combustion at desired combustion rate. For heating of the PM electric heating can be used. The heating of the PM is switched off after engine is sufficiently warm. Battery  
5 voltage of the vehicle, e.g. 12V or in case of hybrid vehicle e.g. 48V or higher voltage may be used to feed electric heater and provide heating current flow through the PM.

[0061] According to the proposed configuration, only one porous medium, instead of e.g. two porous media, may be used for the sake of simplicity  
10 provided that the size of the pores are selected correctly. To achieve better cleaning of the porous medium from the possible accumulated droplets, the porous medium may be completely exposed to the intake air in each engine cycle as illustrated in Figure 1. Unlike the prior art patent application WO2019166094 A1, the application of EGR (exhaust gas recirculation) for  
15 cleaning the PM is not required here due to constant flushing of the PM with fresh air. This can avoid the possibility of clogging of the porous medium by particulate matters coming from EGR.

[0062] As briefly mentioned above, the dual port fuel injection (PFI) structure of the engine comprises the second injector 10 upstream of the intake  
20 flow with respect to the first injector 8. The second injector 10 comprises a nozzle configured to directly inject the fuel into the intake port 3 without being dispersed by a porous medium. Fuel rich core of spray 13 related to the second injector 10 is shown in Figure 1.

[0063] Hence, the second injector 10 may be a conventional fuel injector for  
25 supporting warm-up operation of the engine. In other words, the second injector may only operate when the engine is in a warm-up mode.

[0064] In other words, the second injector 10 is configured to only operate when the temperature of an engine coolant reaches a predetermined temperature, e.g. 80, 90 or 100°C .

[0065] The second injector 10 (conventional PFI) is considered in the intake  
30 port 3, in order to avoid fuel build-up in the PM structure at high load conditions due to high frequency of injection and inadequate time for fuel evaporation. The second injector 10 is arranged at the intake port upstream of the first injector 8, and is more inclined toward the downstream side of the intake port,  
35 e.g. the intake valve 2, than the first injector. The resulting narrow angle of fuel

spray 13 is recommended for to target the spray closer to the intake valve 2 for shortening the response time of the engine at high load demand condition.

[0066] Due to the proposed dual port fuel injection (PFI) structure, the fuel entering the cylinder is already in vapor or in a partially vapor state using a heated PM located in the path of the fuel spray. Therefore a much shorter delay in delivery of the fuel air mixture is expected with a more precise fuel metering. To archive these targets, application of PM with proper pore density, high porosity (>80%) and high heat conductivity may be used. Here the term porosity defines the fraction of void space in PM. High porosities permit large transparency to gas flow and spray through the porous medium without inducing pressure gradient. Application of PM structures reduces spray penetration and therefore can control spray wall interaction which can be a significant source of UHC and CO emissions at cold start. When heated, the porous structure can significantly enhance fuel evaporation, improve homogenization of fuel-air mixture before entering an engine cylinder and reduce spray penetration significantly. The homogenization of fuel-air mixture is partly achieved by a flow of fuel spray through the porous structure which induces small scale turbulence and consequently enhances air entrainment within PM. The amount of liquid fuel reaching the port/valve surface at cold start will be also reduced by breaking up the injected fuel spray into multiple jets and eliminating the rich liquid core of the spray, distributing the split spray on a large surface area of PM and quick evaporating the fuel using high heat transport properties of PM. Since there is a probability of inadequate fuel evaporation during the cold start operation of the engine due to low temperature of the PM and port, the PM may be heated, e.g. by an electric heater. The electric heater will increase the temperature of the PM before the start of the injection process, to a temperature which is proper for evaporation of the fuel at cold start condition. The utilization of cylindrical porous metals with high thermal conductivities (80-160W/m.K), e.g. Ni-Cr-Al or ceramics, e.g. Silicon carbide (SiC) with pore density of 10-20PPI are suggested in this design.

[0067] Figure 2A shows an exploded view of the PM and holder structure and Figure 2B shows a cross-sectional view showing the first injector 8 of the PFI engine provided with the PM and holder structure of Figure 2A according to embodiments of the present disclosure.

[0068] As shown in Figure 2A, the holder 11 may have an adjustable design, in order to be adapted to the thickness of the cylindrical PM 12. In this regard the holder 11 may comprise a top ring 11a and a bottom ring 11b which are respectively arranged on the top and bottom of the PM and thereby sandwiching the PM. A third ring 11c is located above the top ring 11a and maintained at a distance from the latter through a plurality of spacers 11d, 11e, 11f regularly arranged between the rings following an annular arrangement. The third ring 11c is thus positioned around the nozzle tip 9 when the holder 11 is mounted to the injector body 8 as shown in Figure 2B.

[0069] More particularly, several attachment members such as bolts 11g, 11h (only two of them are illustrated in the drawings), may extend longitudinally through the three transverse rings 11a-c so as to maintain them together and attach the resulting assembly (PM and holder) to the injector body of the first injector 8 around the nozzle, thereby holding the first and second rings 11a-b of the holder and the PM at a predefined distance of the nozzle 9 (and of its outlet). The resulting assembly has a longitudinal extension along the direction of the fuel sprayed by the nozzle and along the overall extension of the injector body. The attachment members may be positioned inside the circular envelope defined by the spacers.

[0070] One or both rings may at the same time be configured as a heater. Alternatively or additionally, a coil wrapped around the PM may be used as a heater.

[0071] Figure 3 shows an exploded view and a side view of the PM and a holder structure 11' according to a variant embodiment in which the spacers of Figure 2A have been replaced by nuts, e.g. three nuts 11'd, 11'e and 11'f, for adjusting the distance between the tip of the nozzle (outlet) and the PM. The nuts may be arranged between the first ring 11a and the third ring 11c, against the top surface of the first ring, and may be traversed by the attachment members, e.g. bolts, of Figure 2A so as to be able to adjust the distance of the PM with respect to the nozzle tip by longitudinally moving (by screwing or unscrewing) the nuts along the attachment members. This variant embodiment provides great flexibility in adjusting the distance between the first ring 11a and the nozzle tip and therefore between the PM and the nozzle tip. Thanks to this arrangement the distance between the rings is adjustable to have the best spread of the fuel spray according to different parameters, including the pore

density of the porous medium, the injector nozzle design and the injection pressure.

[0072] As shown in Figures 2A-3, each of these embodiments defines a PM holder that takes the form of an opened frame structure for encasing/housing  
5 the PM and attaching the latter to the injector, while leaving the PM exposed to an outside air flow thanks to the openings of the frame structure.

[0073] Although the above embodiments have been described with respect to a port fuel injection (PFI) structure with two fuel injectors, the above may also apply to a PFI structure according to a further embodiment with only the  
10 first injector 8, the second injector being omitted in this further embodiment.

[0074] The features of the invention will appear more fully from the accompanying drawings following the above mentioned description.

[0075] Throughout the description, including the claims, the term "comprising a" should be understood as being synonymous with "comprising at  
15 least one" unless otherwise stated. In addition, any range set forth in the description, including the claims should be understood as including its end value(s) unless otherwise stated. Specific values for described elements should be understood to be within accepted manufacturing or industry tolerances known to one of skill in the art, and any use of the terms "substantially" and/or  
20 "approximately" and/or "generally" should be understood to mean falling within such accepted tolerances.

[0076] Although the present disclosure herein has been described with reference to particular embodiments, it is to be understood that these embodiments are merely illustrative of the principles and applications of the  
25 present disclosure.

[0077] It is intended that the specification and examples be considered as exemplary only, with a true scope of the disclosure being indicated by the following claims.

## CLAIMS

1. A fuel injected combustion engine, comprising:  
an intake port in controllable fluid communication with a cylinder of  
5 the fuel injected combustion engine;  
fuel delivery means in fluid communication with the intake port and  
positioned to facilitate provision of fuel into the intake port, said fuel delivery  
means comprising a dual port fuel injection (PFI) structure having a first and a  
second injector, wherein  
10 the first injector comprises a nozzle and a three-dimensional porous  
medium positioned between the cylinder and the nozzle, the first injector being  
configured to disperse fuel provided by the nozzle via a plurality of pores in the  
porous medium.
- 15 2. The fuel injected combustion engine according to claim 1, wherein  
only the first of the two injectors comprises a three-dimensional porous medium  
positioned between the cylinder and the nozzle, and/or  
the second injector comprises a nozzle configured to directly inject the fluid into  
the intake port without being dispersed by a porous medium.
- 20 3. The fuel injected combustion engine according to claim 1 or 2,  
wherein  
the second injector is arranged at the intake port upstream of the first injector,  
and/or  
25 the second injector is more inclined toward the downstream side of the intake  
port than the first injector.
4. The fuel injected combustion engine according to any one of the  
preceding claims, wherein  
30 the second injector is configured to only operate when a predefined engine  
warmup condition is satisfied, in particular when the temperature of an engine  
coolant reaches a predetermined temperature.
5. The fuel injected combustion engine according to any one of the  
35 preceding claims, wherein

the first injector comprises a holder configured to hold the porous medium, wherein said holder protrudes into the intake port such that the porous medium is exposed to an air flow in the intake port, and/or

the first injector is arranged within a first injection location and protrudes from  
5 said injection location into the intake port, such that the holder and the porous medium are arranged within the intake port.

6. A fuel injected combustion engine, comprising:  
an intake port in controllable fluid communication with a cylinder of  
10 the fuel injected combustion engine;

fuel delivery means in fluid communication with the intake port and positioned to facilitate provision of fuel into the intake port, said fuel delivery means comprising a port fuel injection (PFI) structure having at least one injector,

15 wherein the at least one injector comprises:  
a nozzle and a three-dimensional porous medium positioned between the cylinder and the nozzle, the at least one injector being configured to disperse fuel provided by the nozzle via a plurality of pores in the porous medium, and a holder configured to hold the porous medium, wherein said holder protrudes  
20 into the intake port such that the porous medium is exposed to an air flow in the intake port.

7. The fuel injected combustion engine according to any one of the preceding claims, wherein the three dimensional porous medium has a pore  
25 density between 10 and 20 PPI (pores per inch), and preferably a porosity greater than 80 percent, and/or  
the three dimensional porous medium has a thermal conductivity between 80 and 160W/m.K.

30 8. The fuel injected combustion engine according to claim 5 or 6, wherein  
the holder has a frame structure which encases the porous medium and has a plurality of openings such that the porous medium is exposed to an air flow in the intake port.

9. The fuel injected combustion engine according to any one of the preceding claims, wherein the engine further comprises a heater configured to increase a temperature of the three-dimensional porous medium, and/or
- 5 the holder comprises a heater configured to increase a temperature of the three-dimensional porous medium.
10. The fuel injected combustion engine according to claim 9, wherein the heater comprises a glow plug inserted at least partially into the three-
- 10 dimensional porous medium.
11. The fuel injected combustion engine according to claim 9 or 10, wherein the heater comprises an electric heater in contact with at least a portion of an outer surface of the three-dimensional porous medium.
- 15 12. The fuel injected combustion engine according to any one of the preceding claims, wherein the three-dimensional porous medium comprises a porous ceramic foam, preferably silicon carbide (SiC).
- 20 13. The fuel injected combustion engine according to any one of the preceding claims, wherein the three-dimensional porous medium comprises a porous metallic foam, preferably Cu or Ni-Cr-Al.
- 25 14. A vehicle comprising a fuel injected combustion engine according to any of claims 1-13.
15. A method for homogenizing an air/fuel mixture of a fuel injected combustion engine, the method comprising:
- 30 injecting fuel provided by a first injector through a three-dimensional porous medium into an intake port of the engine which disperses the injected fuel, and
- injecting fuel provided by a second injector directly into the intake port without being dispersed by a porous medium.

16. The method according to claim 15, wherein the first injector injects fuel during a cold-start of the engine, and/or the second injector only injects fuel when a predefined engine warm-up condition is satisfied, in particular when the temperature of an engine coolant reaches a predetermined temperature.
- 5
17. The method according to any of claims 15 or 16, comprising heating the three-dimensional porous medium during a cold-start of the engine.

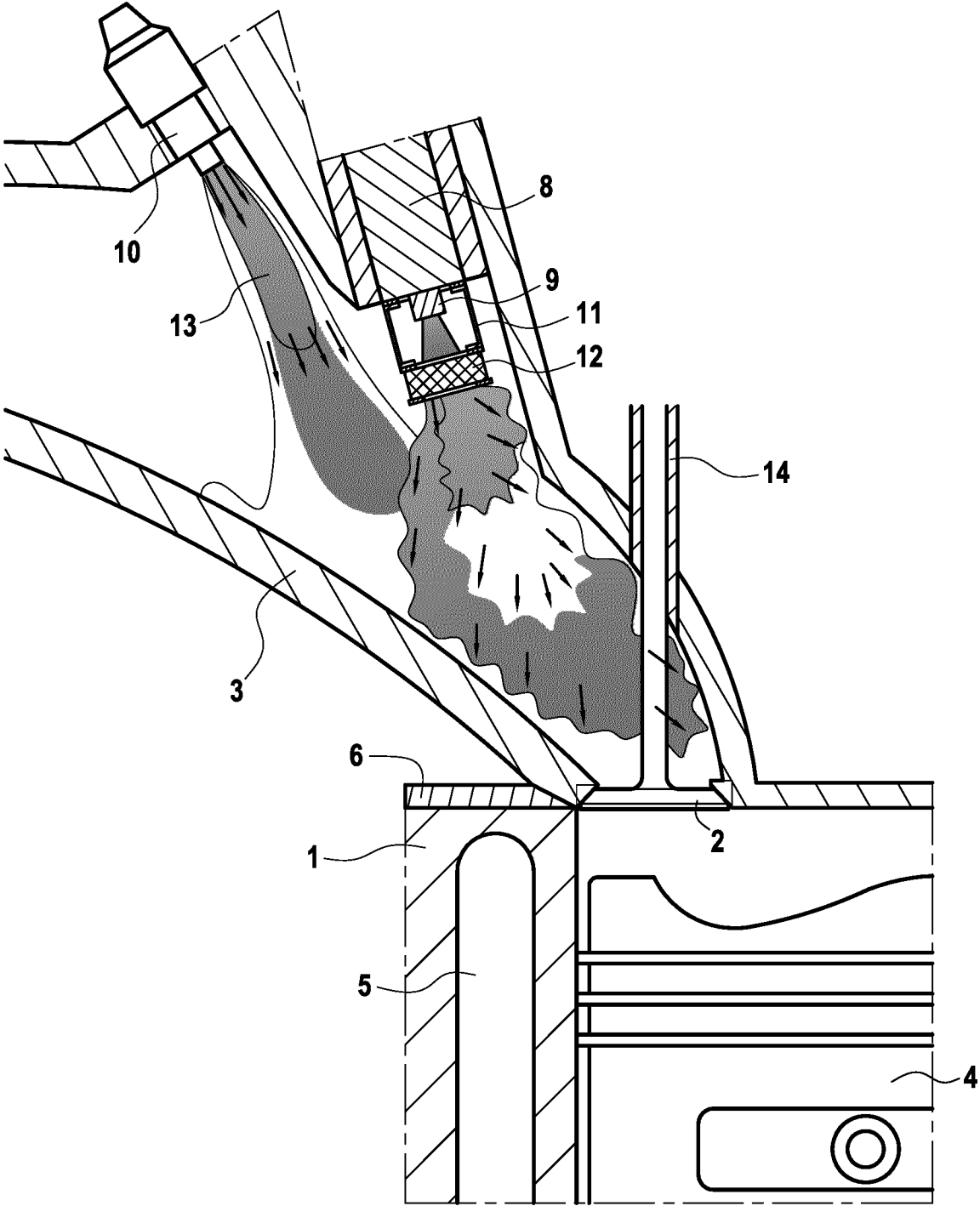


FIG.1

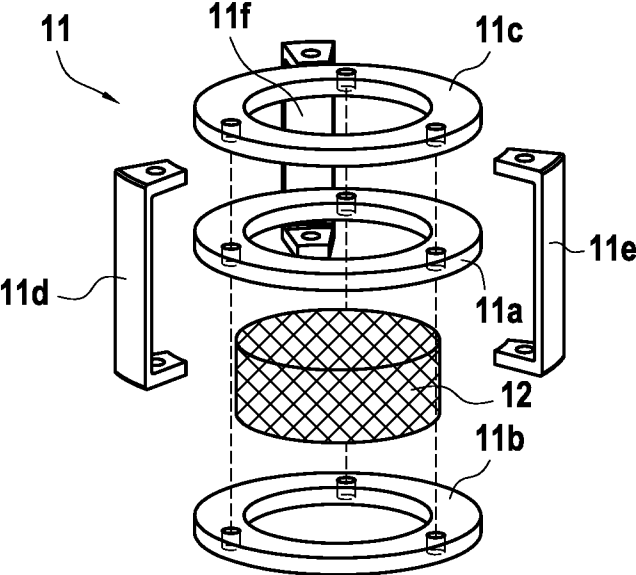


FIG.2A

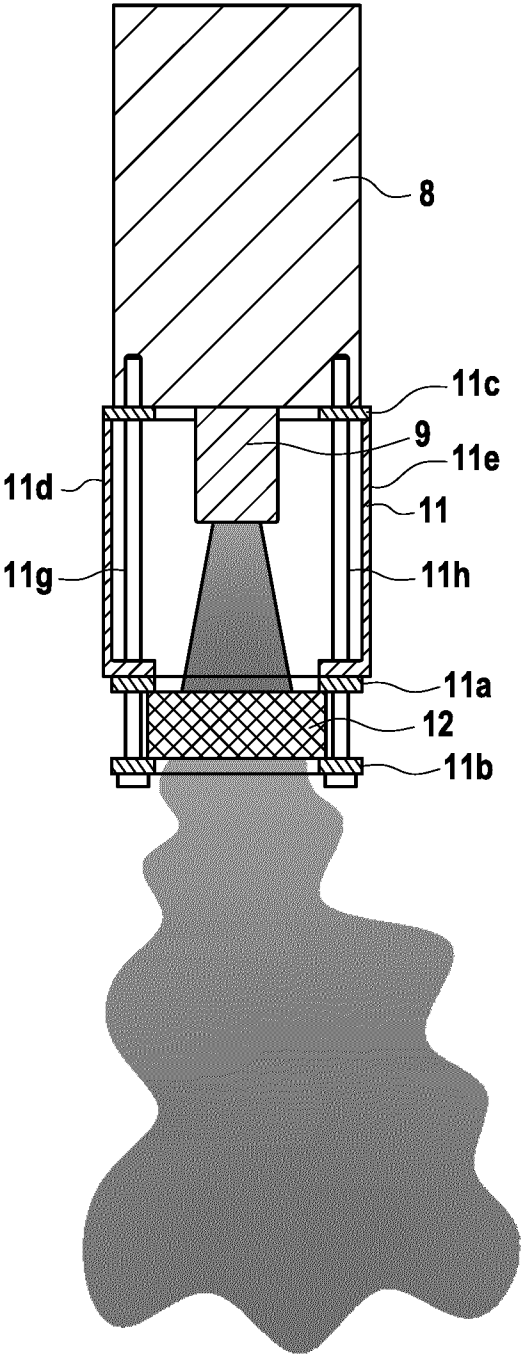


FIG.2B

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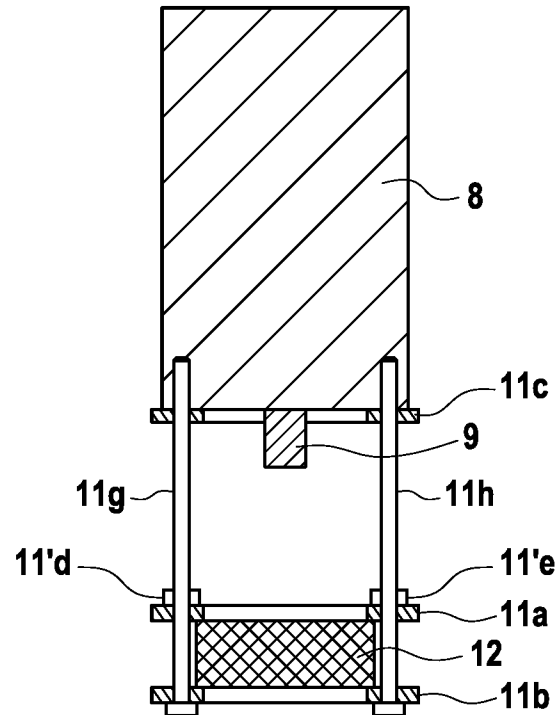
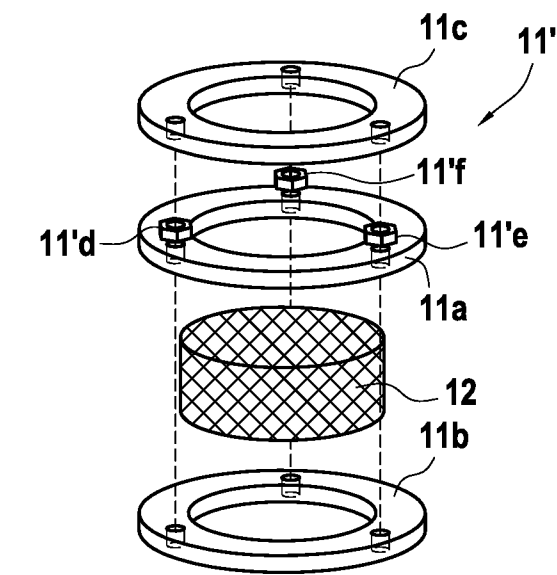


FIG.3

# INTERNATIONAL SEARCH REPORT

International application No  
PCT/EP2020/074838

|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                       |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|
| <b>A. CLASSIFICATION OF SUBJECT MATTER</b><br>INV. F02M43/00 F02M45/08 F02M69/04 F02M53/06<br>ADD.                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                       |
| According to International Patent Classification (IPC) or to both national classification and IPC                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                       |
| <b>B. FIELDS SEARCHED</b><br>Minimum documentation searched (classification system followed by classification symbols)<br>F02M                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                       |
| 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)<br>EPO-Internal, WPI Data                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                       |
| <b>C. DOCUMENTS CONSIDERED TO BE RELEVANT</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                       |
| Category*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | Citation of document, with indication, where appropriate, of the relevant passages                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | Relevant to claim No. |
| X                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | US 5 850 822 A (ROMANN PETER [DE] ET AL)<br>22 December 1998 (1998-12-22)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 1,2,14,<br>15         |
| Y                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | column 4, line 20 - line 36; figure 1                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | 3-13,16,<br>17        |
| Y                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | -----<br>WO 2019/166094 A1 (TOYOTA MOTOR EUROPE<br>[BE]) 6 September 2019 (2019-09-06)<br>cited in the application<br>figures 1-3<br>-----                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 3-13,16,<br>17        |
| <div style="display: flex; justify-content: space-between; align-items: center;"> <div style="display: flex; align-items: center;"> <input type="checkbox"/> Further documents are listed in the continuation of Box C.         </div> <div style="display: flex; align-items: center;"> <input checked="" type="checkbox"/> See patent family annex.         </div> </div>                                                                                                                                                                                                |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                       |
| * Special categories of cited documents :                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                       |
| "A" document defining the general state of the art which is not considered to be of particular relevance<br>"E" earlier application or patent but published on or after the international filing date<br>"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)<br>"O" document referring to an oral disclosure, use, exhibition or other means<br>"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<br>"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<br>"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<br>"&" document member of the same patent family |                       |
| Date of the actual completion of the international search<br><br><div style="text-align: center; font-size: 1.2em;">22 April 2021</div>                                                                                                                                                                                                                                                                                                                                                                                                                                    | Date of mailing of the international search report<br><br><div style="text-align: center; font-size: 1.2em;">06/05/2021</div>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                       |
| Name and mailing address of the ISA/<br>European Patent Office, P.B. 5818 Patentlaan 2<br>NL - 2280 HV Rijswijk<br>Tel. (+31-70) 340-2040,<br>Fax: (+31-70) 340-3016                                                                                                                                                                                                                                                                                                                                                                                                       | Authorized officer<br><br><div style="text-align: center; font-size: 1.2em;">Morales Gonzalez, M</div>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                       |

# INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2020/074838

| Patent document<br>cited in search report |    | Publication<br>date | Patent family<br>member(s) | Publication<br>date |
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