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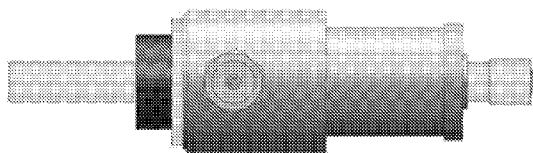


Fig. 3a

(57) Abstract: A heated fuel injector includes an integral heater to flash heat the fuel before the fuel is directly injected into combustion chamber. The heater comprises an upper cylindrical part and a cap part, the upper cylindrical part slides over the injector and covers solenoid sections and most of the neck section above nozzle. This upper cylindrical part includes two sections, the upper section is a hollow cylinder that covers the injector solenoid; the lower section is hollow cylinder whose inner diameter is slightly larger than the diameter of injector neck, the inner surface of the lower section has slots servicing as fuel passages; the cap part encloses the slot section. The injector can improve the combustion efficiency, and reduce pollutants from exhaust.



WO 2017/053519 A1

FLASH VAPOR FUEL INJECTOR

RELATED APPLICATIONS

[0001] This application claims priority to U.S. Provisional Application No. 62/222,013, filed September 22, 2015, and herein incorporated by reference.

GOVERNMENT FUNDING

[0002] This invention was made with government support under Contract No. C10-00570 awarded by Army Research Lab. The government has certain rights in the invention.

FIELD

[0003] The disclosure relates generally to fuel injectors for supplying fuel to a combustion chamber of an internal combustion engine. The disclosure relates specifically to such a fuel injector which is heated to elevate the temperature of the fuel.

BACKGROUND

[0004] Fuel injection systems are used to deliver fuel in many modern engines because of a number of well-known advantages, such as their ability to efficiently and accurately meter fuel flow and the mixture of fuel and air (air/fuel ratio) delivered to an engine. Fuel injection systems can dramatically improve engine performance while reducing engine exhaust gas emissions. Currently available fuel injection systems have heaters that only raise the fuel temperature to room temperature to cold start the engine. In the case of heating the fuel to high temperature, the heaters are mostly furnace heaters that take a long time to bring the fuel temperature to its desired level. The long heating process creates a fuel oxidization (fuel coking) problem when the fuel reacts with dissolved oxygen. This forms deposits on surfaces and eventually clogs up nozzles or pipelines. Thus, there is a need to develop a fuel injection system that overcomes the aforementioned problems.

SUMMARY

[0005] A Direct Fuel Injector (DFI) with an integral heater has been developed to flash heat the fuel before the fuel is directly injected into combustion chamber. There are various applications where heating the fuel is necessary, i.e. improvement of combustion efficiency, reduction of pollutants from exhaust, heavy fuel combustion in current gasoline engines.

[0006] The uniqueness of this heater is its capability to heat low vapor fuel to its vaporization temperature within milli-seconds, while many other heaters only raise fuel temperature to room temperature to cold start the engine. In the case of heating the fuel to high temperature, the heaters are mostly furnace heaters that take a long time to raise the fuel temperature to its desired level. The long heating process creates fuel oxidization (also known as fuel coking) when fuel reacts with dissolved oxygen. This forms a deposit on surfaces and eventually clogs up nozzles or pipelines.

[0007] The proposed flash heating method aims at solving this fuel coking problem by raising the fuel temperature almost instantly and releasing the heated fuel quickly. Thus, the fuel would have little reaction time with dissolved oxygen and the surface from which the fuel emanates, thus eliminating the coking problem.

[0008] Other advantages of the claimed flash method include energy savings due to the compact integrated design of the heater in comparison to standard designs.

[0009] An embodiment of the disclosure is a heated fuel injector for supplying fuel to a fuel consuming device, comprising: a fuel inlet for receiving fuel; a fuel outlet for dispensing fuel from said fuel injector; wherein said fuel inlet is connected to said fuel outlet to form a fuel passage which fuel flows through. In an embodiment, the fuel passage may be directed over a solenoid of the injector for the purpose of cooling. In an embodiment, the heated fuel injector further comprising a heater for heating the fuel. In an embodiment, the heater supplies heat by passing electric current through high resistance element. In an embodiment, the fuel passage further comprises arrays of ultra-thin fuel passages. In an embodiment, the heater comprises an upper cylindrical part and a cap part, the upper cylindrical part slides over the injector and covers solenoid sections and most of the neck section above nozzle, the upper cylindrical part includes two sections, the upper section is a hollow cylinder that covers the injector solenoid; the lower section is hollow cylinder whose inner diameter is slightly larger than the diameter of injector neck, the inner surface of the lower section has slots servicing as fuel passages, and the cap part encloses the slot section. In an embodiment, the slots are equally spaced circumferentially in the inner surface of the lower section. In an embodiment, the number of the slots is 40. In an embodiment, each slot has a rectangle shape. In an embodiment, each slot is a rectangle of 0.006 x 0.170 inch. In an embodiment, the upper cylindrical part and the cap part are made of stainless steel. In an embodiment, the heated fuel injector further comprises a

nichrome wire which is wrapped around the outer wall of slot heating section. In an embodiment, the heated fuel injector further comprises a thin layer of high temperature ceramic potting material covering the outer wall of slot heating section. In an embodiment, the heated fuel injector further comprises four holes which are drilled on the injector neck section between the slot heating section and a nozzle of the injector for fuel flow path. In an embodiment, the four holes are 90 degrees apart from one another. In an embodiment, the heater flash heats fuel from room temperature (in an embodiment, 80 °F) to a desired temperature (in an embodiment, greater than 300 °F) in under one tenth of a second at a required flow rate. In an embodiment, the fuel is pre-heated from a source other than the heater. In an embodiment, the source is the solenoid of the injector. In an embodiment, the heated fuel injector may be made as a retrofit from an existing commercial off-the-shelf (COTS) direct fuel injector. In an embodiment, the heated fuel injector further comprises a first fuel injector and a second fuel injector, the first fuel injector providing a first quantity of high temperature fuel to initiate combustion, and the second fuel injector providing a second quantity of fuel to provide power throughout combustion wherein the first quantity of fuel is less than the second quantity of fuel. In an embodiment, the fuel injector operates with a rail pressure that is lower than a rail pressure under which the fuel injector would operate in the absence of the heated fuel injector. In an embodiment, an engine comprises the heated fuel injector.

[0010] The foregoing has outlined rather broadly the features of the present disclosure in order that the detailed description that follows may be better understood. Additional features and advantages of the disclosure will be described hereinafter, which form the subject of the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] In order that the manner in which the above-recited and other enhancements and objects of the disclosure are obtained, a more particular description of the disclosure briefly described above will be rendered by reference to specific embodiments thereof which are illustrated in the appended drawings. Understanding that these drawings depict only typical embodiments of the disclosure and are therefore not to be considered limiting of its scope, the disclosure will be described with additional specificity and detail through the use of the accompanying drawings in which:

[0012] Fig. 1a is a left view of an upper cylindrical part of a slot heater in accordance with one embodiment disclosed herein;

[0013] Fig. 1b is a cross section view alone line B-B in Fig. 1a;

[0014] Fig. 1c is a right view of an upper cylindrical part of a slot heater in Fig. 1a;

[0015] Fig. 1d is a cross section view alone line A-A in Fig. 1c;

[0016] Fig. 1e depicts details of area C in Fig. 1b.

[0017] Fig. 2 is an elevation view of a cap part of a slot heater in accordance with one embodiment disclosed herein;

[0018] Fig. 3a is an elevation view of a slot heater assembly in accordance with one embodiment disclosed herein;

[0019] Fig. 3b is a right view of the slot heater assembly in Fig. 3a;

[0020] Fig. 3c is an exploded view of the slot heater assembly in Fig. 3a;

[0021] Fig. 4a is a view of direct fuel injector;

[0022] Fig. 4b is a view of the modified direct fuel injector in Fig. 4a;

[0023] Figs. 5a and 5b are flash vapor fuel injector assemblies with nichrome wire heating element embedded in the ceramic;

[0024] Fig. 6 shows flow rate vs. pulse width in a test of flash vapor fuel injector;

[0025] Fig. 7 shows near steady-state temperature vs. pulse width in a test of flash vapor fuel injector;

[0026] Fig. 8 shows outlet fuel temperature vs. volumetric flow rate at different power levels in a test of flash vapor fuel injector;

[0027] Fig. 9 shows heater efficiency determination in a test of flash vapor fuel injector;

[0028] Fig. 10 shows transient temperature response at the start of injection measured at the nozzle exit using 500 °F preheating temperature without fuel;

[0029] Fig. 11 shows transient temperature response at the start of injection measured at the nozzle exit using 500 °F preheating with fuel; and

[0030] Fig 12 shows overlapping 0.1 second time constant curve with transient temperature profile in the case of preheating without fuel at 500 °F.

DETAILED DESCRIPTION

[0031] The particulars shown herein are by way of example and for purposes of illustrative discussion of the preferred embodiments of the present disclosure only and are presented in the cause of providing what is believed to be the most useful and readily understood description of the principles and conceptual aspects of various embodiments of the disclosure. In this regard, no attempt is made to show structural details of the disclosure in more detail than is necessary for the fundamental understanding of the disclosure, the description taken with the drawings making apparent to those skilled in the art how the several forms of the disclosure may be embodied in practice.

[0032] The following definitions and explanations are meant and intended to be controlling in any future construction unless clearly and unambiguously modified in the following examples or when application of the meaning renders any construction meaningless or essentially meaningless. In cases where the construction of the term would render it meaningless or essentially meaningless, the definition should be taken from Webster's Dictionary 3rd Edition.

[0033] An embodiment of the claimed disclosure is directed to a heated fuel injector for supplying fuel to a fuel consuming device. One of the advantages of the claimed disclosure includes its ability to flash heat the fuel quickly to a high temperature coupled with a quick release of the heated fuel. To realize this flash heating, a unique heater which has very thin internal fuel passages, called an integrated slot heater, is designed to heat up fuel quickly and to be able to integrate with a current gasoline direct injector (GDI) with ease. Also, it requires little modification of the cylinder head in a GDI piston engine or housing in a GDI rotary engine.

[0034] In an embodiment, the integrated slot heater comprises arrays of ultra-thin rectangular fuel passages to allow fuel to be heated up quickly as it passes through the vessel. The heating

of the slot heater is realized by heat conduction from an outside heat source. In certain embodiments, nichrome wire is used as an electrical heating element.

[0035] In a further embodiment, the integrated slot heater is also designed to not over-heat the injector solenoid, which operates the valve that controls the passage of the fuel, by locating the heater underneath the injector solenoid. The fuel path is created outside of the original fuel vessel. The inlet fuel path is created in such a way that the inlet fuel picks up the heat from the solenoid and is heated up at the slot heating section before flowing into the nozzle area to be injected. In this way, the injector solenoid is kept cool at all times as long as the fuel is continuously flowing in and injected.

[0036] The impetus for the claimed disclosure is the Army's Single Fuel Initiative to enable all machinery (jeeps, tanks, UAV's, trucks, etc.) to operate on heavy fuel. This is a vast amount of machinery which presently operates on gasoline and a variety of other fuels. The heated DFI would be a relatively easy retrofit on this machinery for enabling operation on heavy fuel, in particular JP-8. Consequently the military market, and possibly the commercial market is immense. The developed design of fast heating feature with existing injection devices can also be used to make or modify the fluid heating devices that require flash heating of fluid, i.e. fuel injectors, water heaters, etc.

[0037] In certain embodiments, the device can be used as a fuel delivering device to start and run gasoline engines with heavy fuels. This would enable military field operations with a single fuel which is a logistical advantage. Non-military uses would include all aspects of transportation since the heated fuel would yield a cleaner burn benefitting the environment.

[0038] The flash vapor fuel injector is capable of heating up fuel from room temperature to above its vaporization temperature within milliseconds. This ensures the initial fuel injection would be at high enough temperature to start the engine with heavy fuel.

[0039] The heater is designed to solve the fuel coking problem at high temperature by flash heating. It also facilitates quick-heating for low thermal diffusivity fluid. Applications include any fluid heating devices or processes that require flash heating capability, flash heated injector, flash heated nozzle, water heaters, etc.

[0040] The heater can be easily integrated with current fuel injectors without modifications of the interior of original fuel injector by using laser welding technique.

[0041] In addition to the heater aspect, the ability of flash heating fuel in a fuel injector has broadened the vision of running low compression ratio engines on flexible fuels, light or heavy, without re-designing the engine. Therefore, a flexible fuel strategy can be realized by equipping internal combustion engines with a flash vapor fuel injector. The central novel features include an integral heater in the DFI that has the experimentally proven capability to heat fuel to the desired high temperature (a) while keeping pace with the 100 shots/sec injection rate and (b) for the initial shots during startup. The heater also is a relatively compact retrofit to an off-the-shelf DFI.

[0042] The purpose of this flash vapor fuel injector is to (1) heat low vapor pressure fuel, i.e. diesel, jet A, JP-8, to vaporization temperatures to facilitate ignition and combustion in a low compression ratio engine; and (2) flash heat the fuel to avoid coking problem that happens at high temperature.

[0043] There have been no flash vapor fuel injectors designed to fulfill the aforementioned purposes for the following reasons: (1) There is no need to heat high vapor pressure fuel. The ignition delays for high vapor pressure fuel at different temperatures are very close. It is only when low vapor pressure is used for running on a low compression ratio engine does it require the heating of the fuel to its vaporization temperature. (2) Coking happens at high temperature. The pre-heating of the fuel in related heated fuel injectors which typically heat the fuel to room temperature, do not deal with this fuel coking problem. (3) In high temperature heating cases, jet A fuel or JP-8 passes various components on aircraft as coolant. The emphasis is on cooling not heating the fuel. Therefore, there has been little development to try to flash heat the fuel to avoid the coking issue.

[0044] The proposed approach of flash heating takes advantage of wire electrical discharge machining (wire EDM) to create a heater with very thin fuel passages (0.006" width). The heater can be integrated with an existing fuel injector by means of laser welding, which ensures the integrity of the existing fuel injector at high pressures. The re-routed fuel flow path helps the cooling of the solenoid coil and improves the efficiency of the heater by minimizing fuel quantity in the heating section and shortening the distance between heating section and nozzle.

[0045] Thin passages (i.e. 0.006" width) in the slot heater provide flash heating capability on low diffusivity fluid. This thin feature is realized by using wire electrical discharge machining

(wire EDM) technology. The rectangular shaped slots (fuel vessel) provide larger contacting area for heat exchange than circular fuel vessel. The thin fuel passage solves low fuel diffusivity problem in the case of heating up fuel. It is capable of heating up the required amount of fuel (flow rate of 0.001 Kg/s) from room temperature (80 F) to desired temperature (300 F) under one tenth of a second.

[0046] A slot heater can be integrated with an off-the-shelf fuel injector to form heater with high-pressure capability, while maintaining the original fuel injector intact (retaining the same injection characteristics), by using laser welding technology to weld the heater and fuel injector together. The injector is designed to integrate the heater with current gasoline direct injector (GDI) or manifold fuel injector (MFI) without modifications of the interior of original fuel injector.

[0047] Another important feature is the cooling feature to the actuator, i.e. a solenoid coil in an embodiment. The heating section is located after the solenoid coil section. The inlet cool fuel functions like coolant to help cool down the solenoid. At the same time, the heat from the solenoid is picked up by the flowing fuel, which then flows into the heating section to be further heated.

[0048] An embodiment of the disclosure is directed to the manufacturing steps for the novel integral heater DFI as described below.

[0049] Referring Fig. 1a to Fig. 5, the integrated slot heater is made of stainless steel 304. It comprises two components, the upper cylindrical part 100 and the cap part 200. The upper cylindrical part 100 slides over the injector 300 and covers solenoid sections and most of the neck section above nozzle. This upper cylindrical part includes two sections. The upper section 101 is a hollow cylinder that covers the injector solenoid. The lower section 121 is a slotted hollow cylinder whose inner diameter is slightly larger than the diameter of injector neck. There are 40 slots 122 equally spaced circumferentially in the cylinder. Each slot is a rectangle of 0.006'' x 0.170''. The length of the cylindrical part and the slot heating section depends largely on specific injector geometry. In an embodiment, 0.6'' is used as the length for slot heating section. AWG 26 nichrome (Ni 80%, Cr 20%) is used as heating element, which is wrapped around the outer wall of slot heating section. The outer wall of slot heating section is covered with a thin layer of high temperature ceramic potting material, which provides electrical insulation (volume resistance 10^{11} ohm-cm) and has decent thermal conductivity (2.16W/m K).

The nichrome wire resistive heater has a total of 20 ohm resistance. Low thermal conductivity ceramic potting material is used as both electrical and thermal insulator covering the heating element.

[0050] The cap part encloses the slot heating section. Four holes are drilled on the injector neck section for fuel flow path. These four holes are 90 degree apart from one another and are located after the slot heating section so that only heated fuel will flow into the injector nozzle. There are two thermocouples embedded in the ceramic potting material. The upper cylindrical part and cap part slide over the injector body and their inner geometry should fit with the outer geometry of the injector being used. Three connection spots are then laser-welded: the upper part and injector (upper part), the upper part and cap part, and cap part and injector (lower section, close to nozzle). The original fuel inlet was closed by welding a stainless steel rod onto it.

[0051] A fuel feed-in hole is opened on the upper cylindrical part and fuel feed-in tube is welded on as fuel inlet. The cold fuel comes in from upper section, flows through injector solenoid section, cools down the solenoid, and then picks up heat at the slot heating section. Finally, it flows into injector nozzle through four fuel flow holes on the injector neck.

[0052] Fig. 6 shows flow rate vs. pulse width in a test of flash vapor fuel injector.

[0053] Fig. 7 shows near steady-state temperature vs. pulse width in a test of flash vapor fuel injector.

[0054] Fig. 8 shows outlet fuel temperature vs. volumetric flow rate at different power levels in a test of flash vapor fuel injector.

EXAMPLES

Example 1

[0055] Steady-state heating test:

[0056] Heating test at various power inputs and flow rates was done using JP-8 fuel. Each test started at room temperature before heater power was turned on. The fuel injector was started simultaneously with the heater to avoid overheating. The fuel injector was operated at a 100 Hz injection rate. The flow rate was varied by changing the pulse width of the fuel

injector. The flow rate was measured using a weighing system that measures the instantaneous mass reduction as the fuel was injected. Temperature was measured with two thermocouples. One was attached to the bottom surface near the nozzle (called nozzle temperature), the other one was placed at the nozzle exit to measure the sprayed fuel temperature (called spray temperature).

[0057] With volumetric flow rate less than 8 mm³/shot at 100 Hz, the measured spray temperature achieved 300 °F mark.

[0058] The test fuel: JP-8 starts vaporization at 320 °F.

[0059] According to the heating test results, it is possible to match the outlet fuel temperature and flow rate data with theoretical results generated using power balance method. Fig. 9 shows the outlet fuel temperature vs. volumetric flow rate at different heater efficiency. The total power input is 245 watts (3.5 A, 20 ohm). As can be seen in Fig. 9, the heating test results consistently fall into the region between 50% and 55% efficiency lines. Therefore, the heater has about 55% efficiency. In an embodiment, this efficiency could improve by adding more insulation on the outer layer of the heater.

[0060] Transient heating tests were done in at least two ways. One is to pre-heat the heater with fuel inside the heater and injector. The other one is to pre-heat the heater without fuel. The heater was maintained at 500 °F for 20 seconds before starting the injection. In an embodiment, once the heater body reaches designated temperature, the pre-heating time does not have influence on the outlet fuel temperature rise. Figure 10 and 11 show the temperature transient at the first few seconds measured at the nozzle exit with the two preheating methods. The heater power was increased as the injection started in order to maintain the exit fuel temperature at a constant level. The heater power started from 32% for pre-heating and 70% for transient heating. The temperature profile was obtained as soon as the injection started. The thermocouple used to measure this spray temperature is a K-type 36 gage bare wire thermocouple. The time constant, which is defined as the time required to reach 63.2% of an instantaneous temperature change is 0.1 second. Fig 12 shows an overlapping 0.1 second time constant curve with transient temperature profile in the case of preheating without fuel at 500 °F.

[0061] While particular embodiments of the present disclosure have been illustrated and described, it would be obvious to those skilled in the art that various other changes and modifications can be made without departing from the spirit and scope of the disclosure. It is therefore intended to cover in the appended claims all such changes and modifications that are within the scope of this disclosure.

[0062] All of the compositions and methods disclosed and claimed herein can be made and executed without undue experimentation in light of the present disclosure. While the compositions and methods of this disclosure have been described in terms of preferred embodiments, it will be apparent to those of skill in the art that variations may be applied to the compositions and methods and in the steps or in the sequence of steps of the methods described herein without departing from the concept, spirit and scope of the disclosure. More specifically, it will be apparent that certain agents which are related may be substituted for the agents described herein while the same or similar results would be achieved. All such similar substitutes and modifications apparent to those skilled in the art are deemed to be within the spirit, scope and concept of the disclosure as defined by the appended claims.

CLAIMS

What is claimed is:

1. A heated fuel injector for supplying fuel to a fuel consuming device, comprising:
a fuel inlet for receiving fuel;

a fuel outlet for dispensing fuel from said fuel injector;

wherein said fuel inlet is connected to said fuel outlet to form a fuel passage which fuel flows through.
2. The heated fuel injector of claim 1, wherein the fuel passage may be directed over a solenoid of the injector for the purpose of cooling.
3. The heated fuel injector of claim 1, further comprising a heater for heating the fuel.
4. The heated fuel injector of claim 3, wherein the heater supplies heat by passing electric current through high resistance element.
5. The heated fuel injector of claim 3, wherein the fuel passage comprises arrays of ultra-thin fuel passages.
6. The heated fuel injector of claim 3, wherein the heater comprises an upper cylindrical part and a cap part, the upper cylindrical part slides over the injector and covers solenoid sections and most of the neck section above nozzle, the upper cylindrical part includes two sections, the upper section is a hollow cylinder that covers the injector solenoid; the lower section is hollow cylinder whose inner diameter is slightly larger than the diameter of injector neck, the inner surface of the lower section has slots servicing as fuel passages, and the cap part encloses the slot section.
7. The heated fuel injector of claim 6, wherein the slots are equally spaced circumferentially in the inner surface of the lower section.

8. The heated fuel injector of claim 7, wherein the number of the slots is 40.
9. The heated fuel injector of claim 6, wherein each slot has a rectangle shape.
10. The heated fuel injector of claim 9, wherein each slot is a rectangle of 0.006 x 0.170 inch.
11. The heated fuel injector of claim 6, wherein the upper cylindrical part and the cap part are made of stainless steel.
12. The heated fuel injector of claim 6, further comprising a nichrome wire which is wrapped around the outer wall of slot heating section.
13. The heated fuel injector of claim 12, further comprises a thin layer of high temperature ceramic potting material covering the outer wall of slot heating section.
14. The heated fuel injector of claim 6, further comprises four holes which are drilled on the injector neck section between the slot heating section and a nozzle of the injector for fuel flow path.
15. The heated fuel injector of claim 14, wherein the four holes are 90 degrees apart from one another.
16. The heated fuel injector of claim 1, wherein the heater flash heats fuel from room temperature to a desired temperature in under one tenth of a second at a required flow rate.
17. The heated fuel injector of claim 3, wherein the fuel is pre-heated from a source other than the heater.
18. The heated fuel injector of claim 3, the source is the solenoid of the injector.
19. The heated fuel injector of claim 1, wherein the heated fuel injector may be made as a retrofit from an existing commercial off-the-shelf (COTS) direct fuel injector.

20. The heated fuel injector of claim 1, further comprising a first fuel injector and a second fuel injector, the first fuel injector providing a first quantity of high temperature fuel to initiate combustion, and the second fuel injector providing a second quantity of fuel to provide power throughout combustion wherein the first quantity of fuel is less than the second quantity of fuel.
21. The heated fuel injector of claim 1, wherein the fuel injector operates with a rail pressure that is lower than a rail pressure under which the fuel injector would operate in the absence of the heated fuel injector.
22. An engine, comprising the heated fuel injector of claim 1.

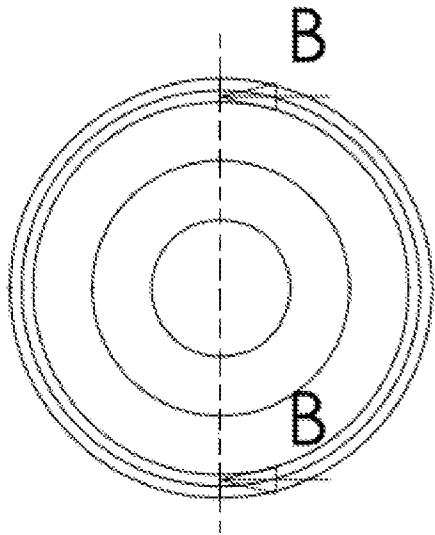


Fig. 1a

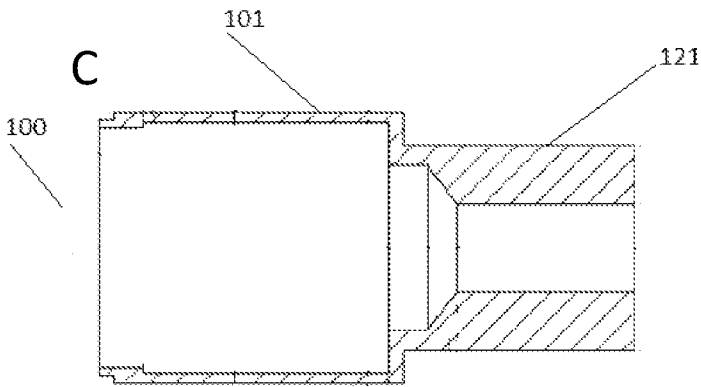


Fig. 1b

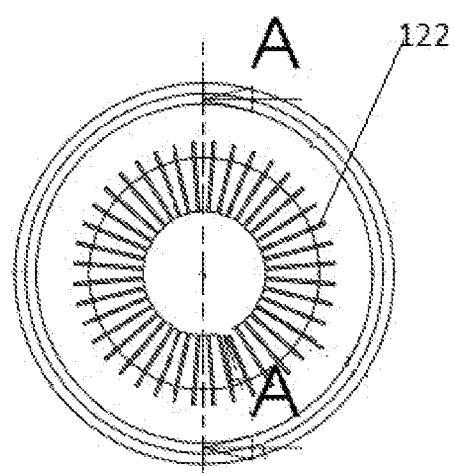


Fig. 1c

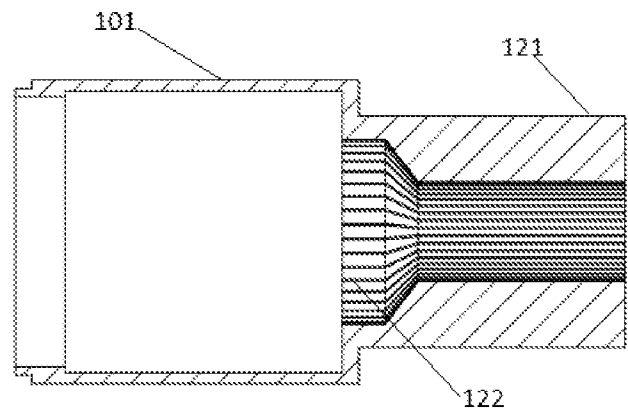


Fig. 1d

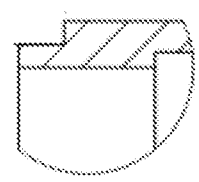


Fig. 1e

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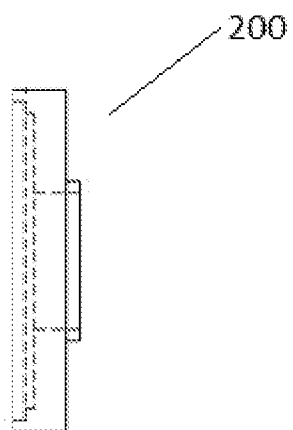


Fig. 2

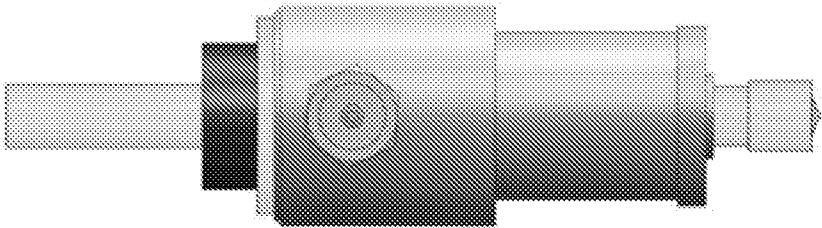


Fig. 3a

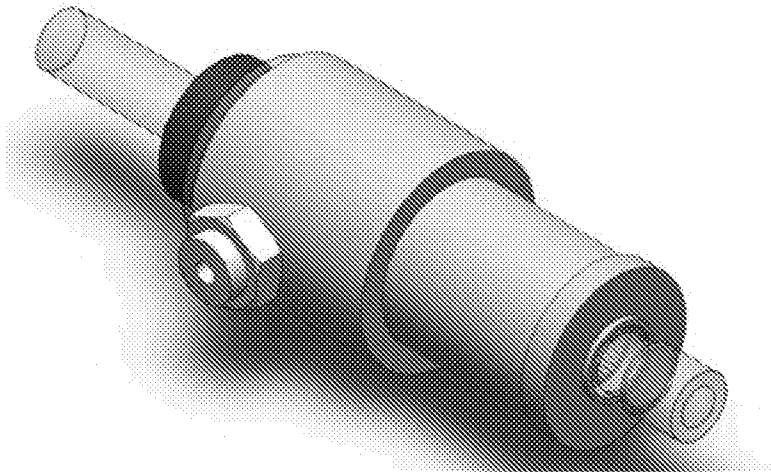


Fig. 3b

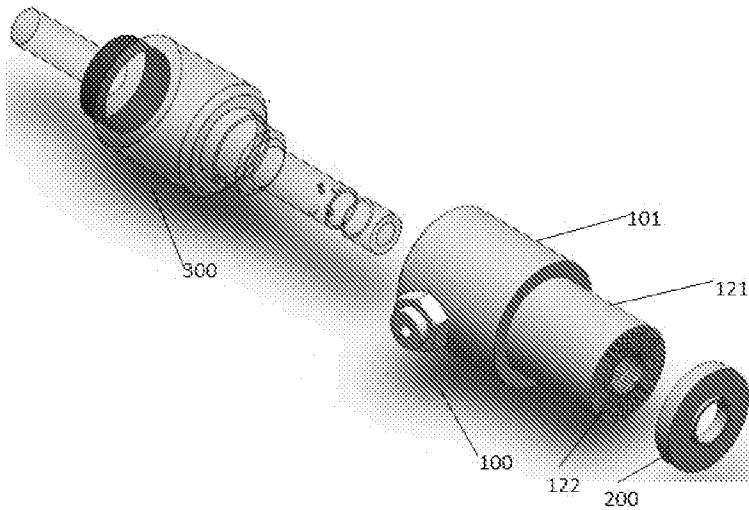


Fig. 3c

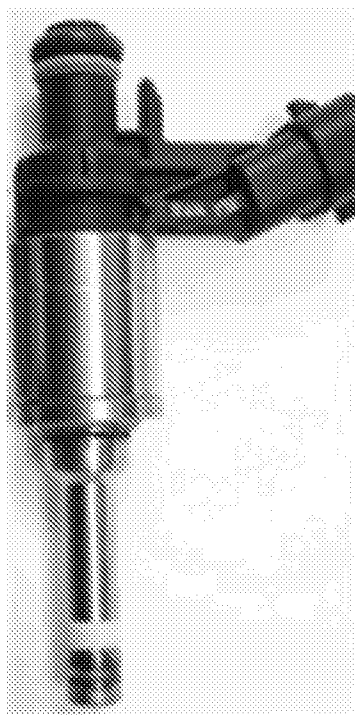


Fig. 4a

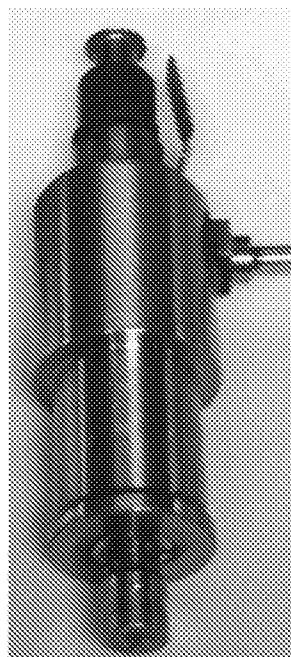


Fig. 4b

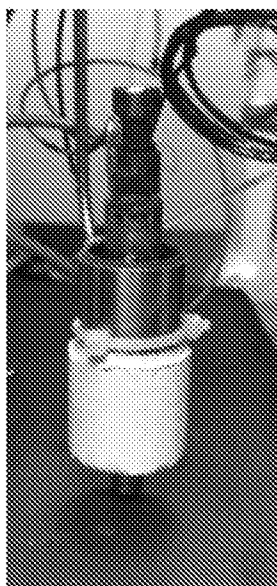


Fig. 5a

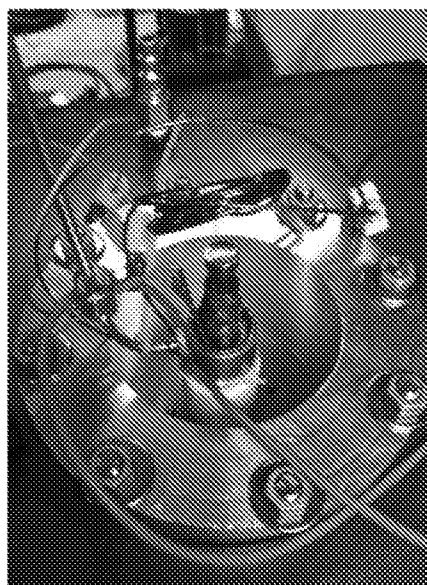


Fig. 5b

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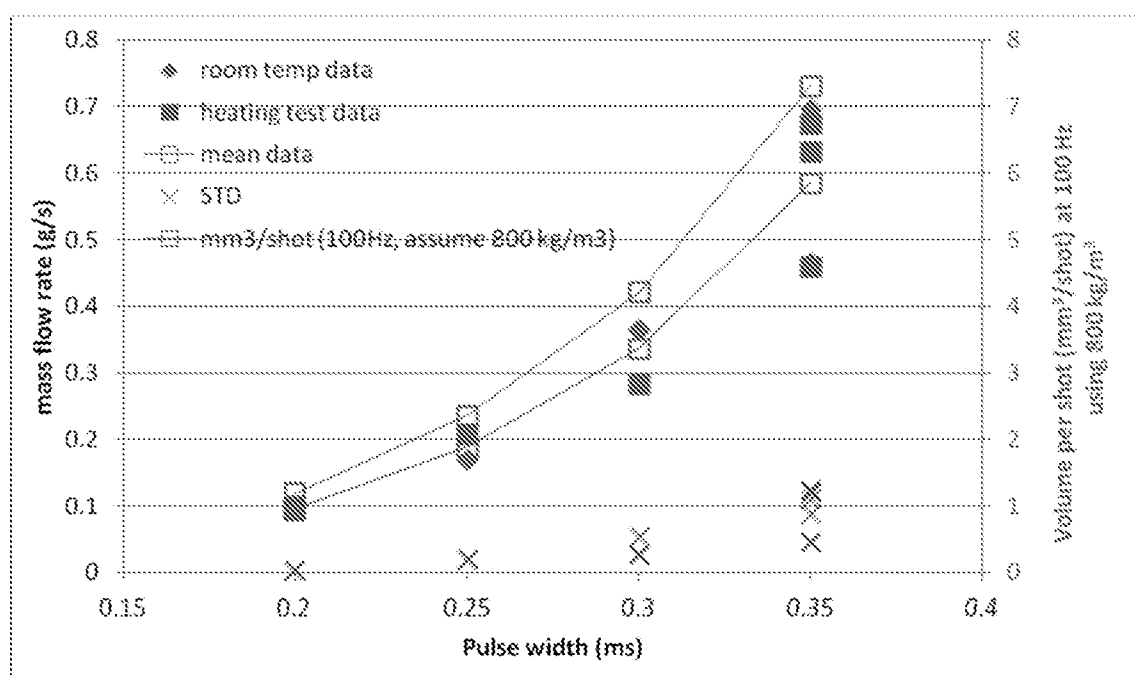


Fig. 6

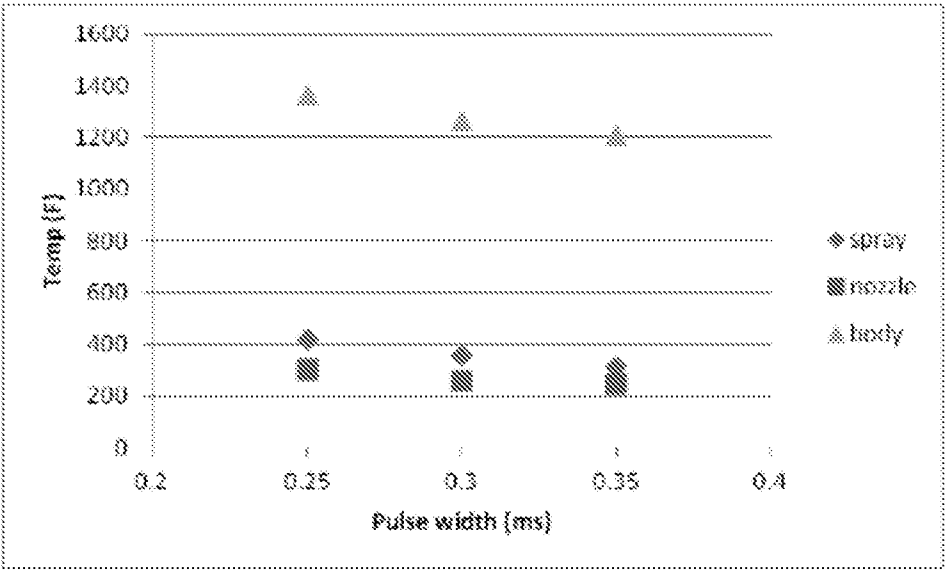


Fig. 7

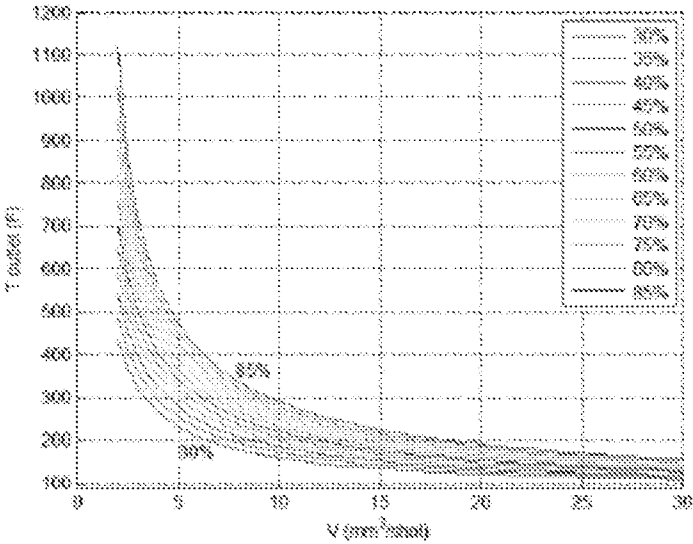


Fig. 8

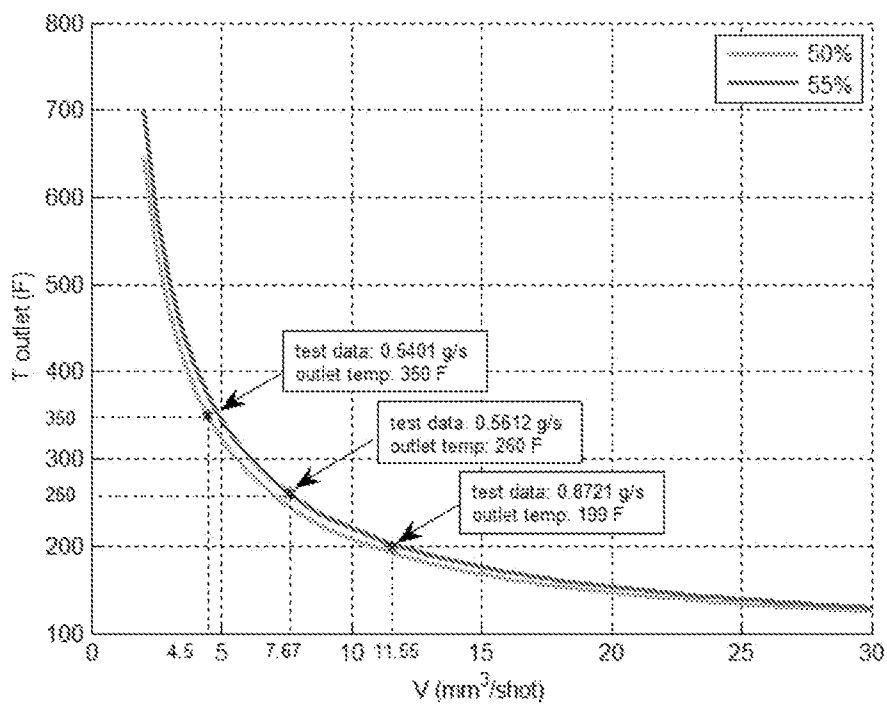


Fig. 9

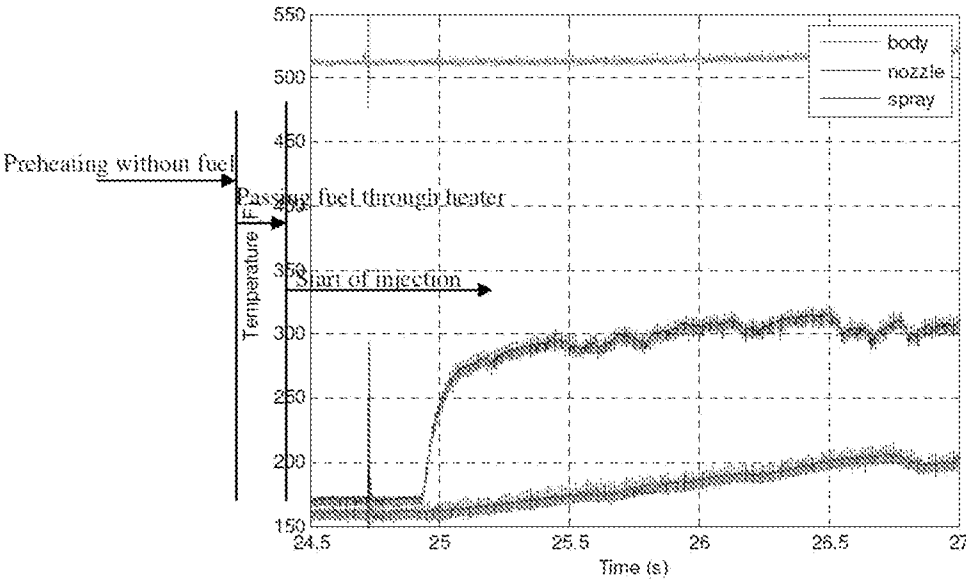


Fig. 10

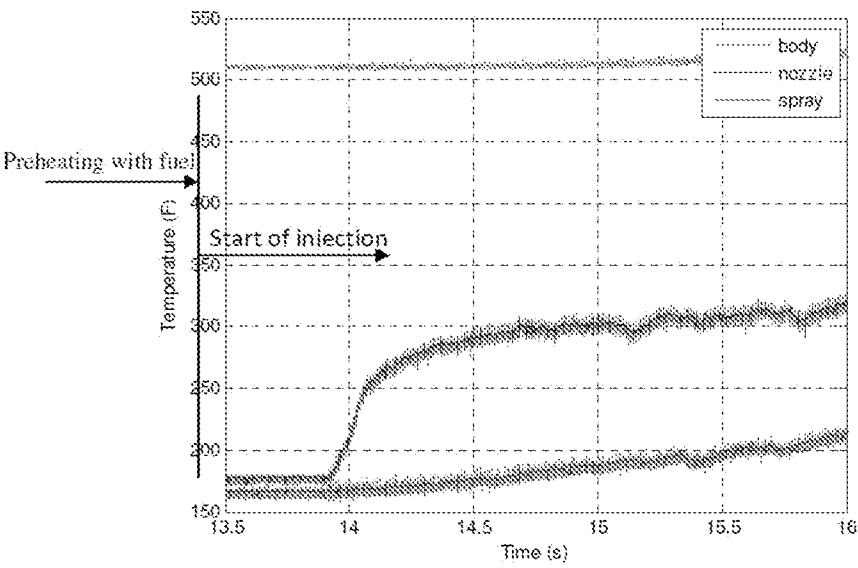


Fig. 11

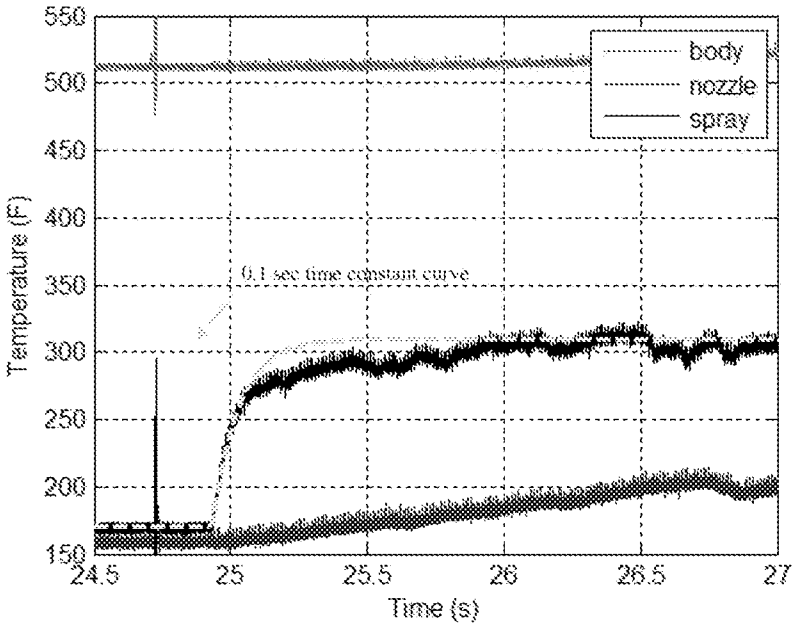


Fig. 12

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 2016/053020

A. CLASSIFICATION OF SUBJECT MATTER <i>F02M 53/06 (2006.01)</i> <i>F02M 31/125 (2006.01)</i> 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) F02M 31/125, 53/00, 53/02, 53/04, 53/06, F23D 11/00, 11/44, 11/46 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) PatSearch (RUPTO internal), USPTO, PAJ, Esp@cenet, DWPI, EAPATIS, PATENTSCOPE		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	KR 20080021277 A (DOOSAN INFRACORE CO., LTD) 07.03.2008, fig. 1, 2, abstract	1-4, 17, 18, 22
Y		5, 12, 13
Y	SU 17925 A1 (PRIGOROVSKY M. I.) 30.09.1930, fig. 1, claims	5
Y	US 2005/0263136 A1 (SHAUN THOMAS RIGNEY) 01.12.2005, fig. 18-21, par. [0142]	12, 13
A	US 2005/0252987 A1 (VINCENC SELAK) 17.11.2005	1-22
☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.		
*	Special categories of cited documents:	“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
“A”	document defining the general state of the art which is not considered to be of particular relevance	
“E”	earlier document 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	
Date of the actual completion of the international search 07 December 2016 (07.12.2016)		Date of mailing of the international search report 29 December 2016 (29.12.2016)
Name and mailing address of the ISA/RU: Federal Institute of Industrial Property, Berezhkovskaya nab., 30-1, Moscow, G-59, GSP-3, Russia, 125993 Facsimile No: (8-495) 531-63-18, (8-499) 243-33-37		Authorized officer S. Bushin Telephone No. 8-499-240-25-91