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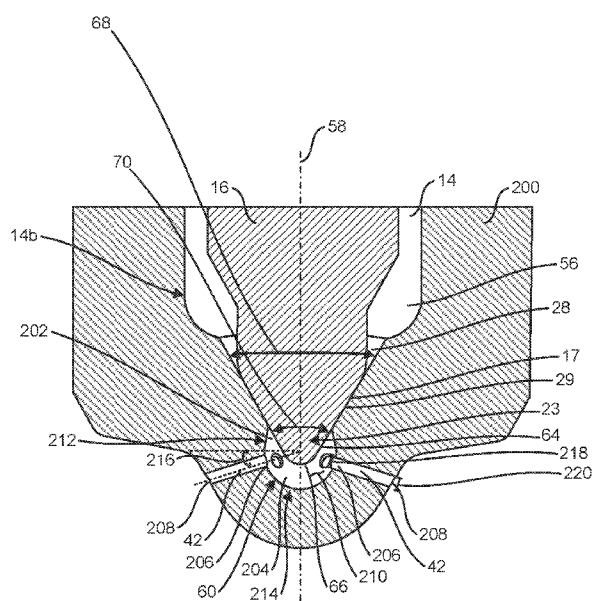


FIG. 2B

(57) Abstract: Disclosed herein are devices, systems and methods relating to fuel injectors. A fuel injector nozzle can include an injector cavity, a sac, and one or more spray holes. The sac can extend from an injector cavity distal end. In examples, a vertical cross section of the sac can be pear shaped. The sac can include a sac volume defined by a diverged portion that extends from the injector cavity distal end and a converged portion that extends from the diverged portion. The one or more spray holes can extend from an inlet opening at the sac volume to an outlet opening. The inlet opening can be positioned within the sac to reduce cavitation caused by vapor collapse at the sac.

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FUEL INJECTOR DEVICES, SYSTEMS, AND METHODS

FIELD OF THE DISCLOSURE

[0001] The present disclosure generally relates to fuel injectors for an engine, and more specifically, to fuel injectors that produce reduced cavitation.

BACKGROUND

[0002] Diesel engines use high pressure in the delivery of fuel for combustion. When force is applied to fluid, vapor cavities can be produced therein. The cavities often form in areas of relatively low pressure. When higher pressure is subsequently experienced in the area of a cavity, the cavity implodes and produces a shockwave. These implosions and shockwaves can produce wear on parts that experience them. Collapsing voids that implode near a metal surface can cause cyclic stress through repeated implosion. These may result in surface fatigue of the metal causing a type of wear also called "cavitation."

[0003] Diesel engines use fuel injectors having needle valves to deliver fuel. When such needle valves are open, fuel flows therein. Accordingly, needle valves are susceptible to cavitation. Needle valves typically have an area referred to as a "sac." Increasing the volume of the sac also leads to a decrease in the efficiency of the engine and increases the undesirable emissions produced thereby due to unburnt fuel or otherwise.

[0004] As is generally known in the art, to control emission efficiency especially in such large engines, it is desirable to provide a large cup flow while reducing the sac volume. In prior art systems, large cup flow is accomplished by providing large spray holes in the nozzle of the fuel injector, which generally requires a larger sac volume. Moreover, placement of the fuel delivery holes in the fuel injector can, in some instances, increase cavitation of the fuel, which over time degrades the performance of the fuel injector. Further development in this technology is needed.

[0005] Turning to FIG. 1, an example of a fuel injector nozzle 10' that is known in the art is shown. In particular, FIG. 1 shows a sectional view of a distal end of a fuel injector having a

needle valve 16' with a needle valve tip 66'. The needle valve 16' is configured for reciprocal movement within a connected fuel injector. In addition, the fuel injector nozzle has an injector cavity 14', a sac 60', and one or more spray holes 42'. Flow-guiding surface 64' is formed at a flow-guiding surface angle 70' that is greater than seat angle 68. The effect of flow-guiding surface angle 70' being larger than seat angle 68' is that flow-guiding surface 64' does not contact the fuel flow surface 29' of a valve seat 28' and a resulting gap 72' between fuel flow surface 29' and flow-guiding surface 64' increases gradually as the distance from contact surface 17' toward the needle valve tip 66' increases. In the fuel injector shown here, the seat angle 68 is about 60 degrees and the flow-guiding surface angle 70' is between 64 and 69 degrees. Extending from the sac 60' are spray holes 42' through which fuel can exit the fuel injector nozzle 10'.

SUMMARY

[0006] The present disclosure advantageously provides design considerations for fuel injectors to reduce cavitation produced therein, especially in high mass flow rate applications and where there is a limited number of spray holes required. In examples, the present disclosure includes a fuel injector with a modified sac geometry.

[0007] In a first examples, a fuel injector nozzle can include an injector cavity, a sac, and one or more spray holes. The sac can extend from an injector cavity distal end. In examples, a vertical cross section of the sac can be pear shaped. The sac can include a sac volume defined by a diverged portion that extends from the injector cavity distal end and a converged portion that extends from the diverged portion. The one or more spray holes can extend from an inlet opening at the sac volume to an outlet opening. The inlet opening can be positioned within the sac to reduce cavitation caused by vapor collapse at the sac.

[0008] Continuing with the first example, the one or more spray holes can have a plurality of spray holes. The inlet opening of one or more spray holes in the plurality of spray holes can be positioned at the diverged portion of the sac. In examples, a portion of the inlet opening can be positioned at the diverged portion of the sac. In examples, an entirety of the inlet opening can be positioned at the diverged portion of the sac. In examples, the inlet opening can

be positioned about halfway between a sac proximal end and a sac distal end. An inlet opening diameter of the one or more spray holes can be greater than an outlet opening diameter of the one or more spray holes. Each spray hole in the one or more spray holes can have a spray hole angle between about 13 degrees and 22 degrees.

[0009] Further toward the first example, a valve seat can be positioned at the injector cavity distal end. A seat angle of the valve seat can be between about 60 degrees and about 90 degrees. The seat angle can be about 75 degrees. The seat angle can be about 90 degrees.

[0010] In a second example, a fuel injector can include a needle valve and a fuel injector nozzle. The needle valve can have a needle valve tip and can be configured to reciprocally move along a central axis between an open and a closed position. A fuel injector nozzle can include an injector cavity, a sac, and one or more spray holes. The sac can extend from an injector cavity distal end. The sac can include a sac volume defined by a diverged portion that extends from the injector cavity distal end and a converged portion that extends from the diverged portion. The one or more spray holes can extend from an inlet opening at the sac volume to an outlet opening. The inlet opening can be positioned within the sac to reduce cavitation caused by vapor collapse at the sac.

[0011] Continuing with the second example, the one or more spray holes can be a plurality of spray holes. The inlet opening of one or more spray holes in the plurality of spray holes can be positioned at the diverged portion of the sac. In examples, either a portion or an entirety of the inlet opening can be positioned at the diverged portion of the sac.

[0012] Further toward the second example, the fuel injector can further include a valve seat positioned at the injector cavity distal end. A seat angle of the valve seat can be between about 60 degrees and about 90 degrees. In examples, the seat angle can be between about 75 degrees and about 90 degrees.

[0013] Various methods relating to supplying and routing fuel are disclosed herein. A method can include supplying a fuel past a needle valve configured to reciprocally move along a central axis within an injector cavity between an open and a closed position. The injector cavity can be formed within a fuel injector nozzle. The method can include routing the fuel into a

diverged portion, which extends from the injector cavity, of a sac when the needle valve is in an open position. The method can include routing the fuel into a converged portion, which extends from the diverged portion, of the sac extending from the diverged portion, each of the diverged portion and the converged portion defining a sac volume. The method can include routing the fuel through one or more spray holes that extend from an inlet opening at the sac volume to an outlet opening. The inlet opening can be positioned within the sac to reduce cavitation caused by vapor collapse at the sac.

[0014] Methods disclosed herein can include various features discussed in relation to devices and systems discussed herein. For example, either a portion or an entirety of the inlet opening can be positioned at the diverged portion of the sac. In examples of the method, the fuel injector nozzle can further include a valve seat positioned at an injector cavity distal end. A seat angle of the valve seat can be between about 60 degrees and about 90 degrees. In examples of the method, the one or more spray holes can have a plurality of spray holes, and the inlet opening of one or more spray holes in the plurality of spray holes can be positioned at the diverged portion of the sac.

[0015] Additional features and advantages of the present disclosure will become apparent to those skilled in the art upon consideration of the following detailed description of the illustrative embodiments exemplifying the disclosure as presently perceived.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] The above-mentioned and other features and advantages of this disclosure, and the manner of obtaining them, will become more apparent, and will be better understood by reference to the following description of the exemplary embodiments taken in conjunction with the accompanying drawings, wherein:

[0017] FIG. 1 is a sectional view of a distal end of a known fuel injector;

[0018] FIG. 2A is a cross-sectional schematic view of a fuel injector according to principles of the present disclosure;

[0019] FIG. 2B is a sectional view of a distal end of the fuel injector of FIG. 2A; and

[0020] FIG. 3 is a flowchart of a method of operating an engine, according to principles of the present disclosure.

[0021] Corresponding reference characters indicate corresponding parts throughout the several views. Although the drawings represent embodiments of various features and components according to the present disclosure, the drawings are not necessarily to scale and certain features can be exaggerated in order to better illustrate and explain the present disclosure. The exemplification set out herein illustrates an embodiment of the invention, and such an exemplification is not to be construed as limiting the scope of the invention in any manner.

DETAILED DESCRIPTION OF THE DRAWINGS

[0022] For the purposes of promoting an understanding of the principles of the present disclosure, reference is now made to the embodiments illustrated in the drawings, which are described below. The exemplary embodiments disclosed herein are not intended to be exhaustive or to limit the disclosure to the precise form disclosed in the following detailed description. Rather, these exemplary embodiments were chosen and described so that others skilled in the art can utilize their teachings. It is not beyond the scope of this disclosure to have a number (e.g., all) the features in a given embodiment to be used across all embodiments.

[0023] As an initial matter, throughout this disclosure, the words “distal,” “lower,” and words of similar effect will correspond to portions of the fuel injector that are downstream relative to other portions in terms of the flow of fuel from the injector to the combustion chamber of an engine, such as the injector openings or spray holes. Similarly, the words “proximal,” “upper,” and words of similar effect will correspond to portions of the fuel injector that are upstream of the downstream portions.

[0024] Referring to FIGS. 2A and 2B, a fuel injector 10 according to principles of the present disclosure is shown. FIG. 2A shows a cross-sectional schematic view of the fuel injector 10. FIG. 2B shows a sectional view of a distal end of the fuel injector 10 of FIG. 2A. Though the present disclosure describes particular configurations of fuel injectors 10, the features of the present disclosure can be used on any fuel injector 10 compatible with the features of the present

disclosure. For example, the fuel injector 10 can be in the form of an Extreme Pressure Injection (XPI) fuel injector 10.

[0025] As illustrated here, the fuel injector 10 includes a fuel injector nozzle 12 containing an injector cavity 14, which has an injector cavity proximal end 14a and an injector cavity distal end 14b, and a needle valve 16 movably arranged within the injector cavity 14 for reciprocal movement therein. The needle valve 16 includes a needle valve proximal end 22 with a guide portion 24 that is sized and positioned to be slidably received within walls of the injector cavity 14. The needle valve proximal end 22 and a needle valve distal end 23 can be opposing ends of the needle valve 16. The needle valve 16 also includes a contact surface 17 positioned at the needle valve distal end 23 for engaging a valve seat 28, which is formed at a distal end of the fuel injector nozzle 12, when the needle valve 16 is in the closed position, as shown in FIGS. 2A and 2B. The needle valve 16 can be biased in the closed position by a biasing member 32 (e.g., a spring or other resilient member) that can be located in a biasing member chamber 34 formed within the injector cavity 14.

[0026] A needle valve actuating system 35 can cause the needle valve 16 to move (e.g., reciprocate) within the injector cavity 14. The needle valve actuating system 35 can include a proximal control volume 36 formed in the fuel injector nozzle 12 and positioned proximate to the needle valve proximal end 22. The needle valve actuating system 35 can also include a control volume supply passage 38 that directs fuel from a fuel supply passage 40 to the proximal control volume 36. The fuel supply passage 40 also delivers fuel to biasing member chamber 34 for delivery to one or more spray holes 42 when the needle valve 16 is in an open position, as discussed further below. The needle valve actuating system 35 also includes a drain passage 44 for draining fuel from the proximal control volume 36 when commanded by an injection control valve (not shown) for controlling the flow of fuel through drain passage 44 so as to cause controlled movement of the needle valve 16 between open and closed positions.

[0027] When commanded by an actuator assembly (not shown), fuel will flow through a series of passages with orifices to create pressure differentials across the needle valve 16 to thereby cause the needle valve 16 to move. To begin, the proximal control volume 36 can be filled with pressurized fuel. Then, a pressure decrease at the proximal control volume 36 is

created by having less fuel flowing through a supply orifice 50 in the control volume supply passage 38 than is drained through a drain orifice 46, which has a larger flow area than the supply orifice 50, in the drain passage 44. At the same time, fuel flows into the fuel supply passage 40 and then through a transfer passage 52 past a transfer orifice 54 into a distal control volume 56. Because the transfer orifice 54 has a larger flow area than the supply orifice 50, pressure in the distal control volume 56 is about equal to the pressure in control volume supply passage 38 and fuel supply passage 40. The result is a pressure differential between the needle valve proximal end 22 and the needle valve distal end 23, which causes the needle valve 16 to move along a central axis 58 of the needle valve 16 from the closed position shown here to the open position (not shown).

[0028] As the needle valve 16 begins to lift, fuel enters a sac 60 located between the fuel injector nozzle 12. Pressure in the sac 60, and by extension at the needle valve distal end 23, increases, thereby assisting in lifting the needle valve 16. At the same time, fuel begins to exit the sac 60 through one or more spray holes 42 to be delivered into an engine combustion chamber (not shown).

[0029] When the actuator assembly (not shown) is de-energized or commanded to stop fuel flow, fuel will cease flowing through the drain passage 44, and fuel pressure will again begin to build in the proximal control volume 36. At the same time, fuel drains from the sac 60 via the one or more spray holes 42, decreasing pressure in the sac 60 and in the distal control volume 56. The result is a pressure differential between the proximal control volume 36 and distal control volume 56, which causes the needle valve 16 to move from the open position to the closed position. It follows that reciprocal movement of the needle valve 16 can be achieved by controlling the pressure differentials between the proximal control volume 36 and the distal control volume 56 to thereby move the needle valve 16 between the open and closed positions.

[0030] Referring now to FIG. 2B, a cross-sectional view of a distal portion of the fuel injector 10 is shown. As previously noted, the needle valve 16 includes the contact surface 17. Adjacent to the contact surface 17 is a flow-guiding surface 64 that extends toward a needle valve tip 66 located at the needle valve distal end 23. In some instances, the flow-guiding surface has a different (usually greater) surface angle than the contact surface, resulting in a gap where

between portions of the flow-guiding surface that overhang the valve seat. Under these circumstances, the flow-guiding surface 64 can terminate at a circumferential corner where the contact surface meets the flow-guiding surface such that this corner extends to join with the needle valve tip 66. Note that some needle valves 16 may not include such a corner, for instance where the flow-guiding surface and contact surface have the same angle. The flow-guiding surface 64 is generally straight and forms a conical frustum about the needle valve 16 centered along on the central axis 58. In this regard, the contact surface can have

[0031] Extending from the valve seat 28 toward the sac 60 or a spray hole 42 in the one or more spray holes 42 is a fuel flow surface 29, which is an extension of the valve seat 28 and which can be at the same angle as the valve seat 28. The valve seat 28 and fuel flow surface 29 can be in the form of a conical frustum or a frusto-conical surface centered along the central axis 58. Thus, the valve seat 28 and the fuel flow surface 29 can be at the same angle. As shown, the valve seat 28 and fuel flow surface 29 has a seat angle 68 centered on the central axis 58.

[0032] It has been determined that improved resistance to cavitation in the sac 60 can be achieved by incorporating certain design aspects of into the nozzle design, in particular, with respect to the sac 60, the valve seat 28, and the one or more spray holes 42 thereof. Details of the sac 60, the valve seat 28, and the one or more spray holes 42 are discussed further below.

[0033] As can be seen in comparing FIGS. 2A and 2B to FIG. 1, in contrast to the spherical shaped sacs in known fuel injectors 10' (e.g., as seen in FIG. 1), sacs 60 in the present disclosure can have a pear-shaped vertical cross section (as seen in FIGS. 2A and 2B). For example, as noted prior, the sac 60 can extend from an injector cavity distal end 14b. And as the sac 60 extends along the axis, a horizontal cross section of the sac 60 can distend to a point and then from at or around that point taper to a close. It is noted that the sac 60 can be axisymmetric about the central axis 58. In this regard, the sac 60 can include a sac 60 volume defined by a diverged portion 202 that extends from the injector cavity distal end 14b and a converged portion 204 that extends from the diverged portion 202.

[0034] With reference to FIGS. 2A and 2B again, one or more spray holes 42 included in the sac 60 can extend from an inlet opening 206 at the sac 60 volume to an outlet opening 208 that is open to an outside of the fuel injector nozzle 200. The inlet opening 206 can be positioned

within the sac 60 to reduce cavitation caused by vapor collapse at the sac 60. It should be noted that, in examples, the diverged portion 202 of the sac 60 can cause an increase of pressure in the sac 60. In addition, or in alternative, while discussed herein as extending from the injector cavity distal end 14b, it is appreciated that the diverged portion 202 can be located anywhere within the sac volume. For example, the diverged portion 202 can be positioned either at the injector cavity distal end 14b or further downstream of the injector cavity distal end 14 within the sac volume.

[0035] For manufacturing purposes, the pear-shaped sac 60 can be formed using a multi-step process. For example, the sac 60 and a portion of the injector cavity 14 can be formed via a central drilling. The central drilling can result in a generally spherical sac 60. In examples, the sac 60 can be formed within the fuel injector nozzle 200 via a chemical process, which can widen the generally spherical sac 60 until it becomes pear shaped.

[0036] The inlet opening 206 can be positioned at various points along a wall 210 of the sac 60. In examples, the inlet opening 206 can be positioned about halfway between a sac proximal end 212 and a sac distal end 214. In examples, a portion or an entirety of the inlet opening 206 of one or more spray holes 42 in the plurality of spray holes 42 can be positioned at the diverged portion 202 of the sac 60.

[0037] In examples, the one or more spray holes 42 can have a plurality of spray holes 42. For example, the plurality of spray holes 42 can include 6 to 12 spray holes 42. In examples, the plurality of spray holes 42 includes 8 spray holes 42. In other examples, the plurality of spray holes 42 includes 10 spray holes 42. Each of the spray holes 42 can be radially spaced about in a plane extending through the sac 60. In some such examples, each of the spray holes 42 can be equally spaced apart in the plane.

[0038] Along with or in alternative to the number of spray holes 42, the one or more spray holes 42 can be defined by a spray hole angle 216 and diameters along the one or more spray holes 42. Each spray hole 42 can include an inlet opening 206 that has an inlet opening diameter 218 and an outlet opening 208 that has an outlet opening diameter 220. The spray hole angle 216 can be the angle formed as the spray hole 42 extends distally from a plane that orthogonally extends through the central axis 58. In this regard, each spray hole 42 in the one or

more spray holes 42 can have a spray hole angle 216 between about 13 degrees and 22 degrees. For example, the spray hole angle 216 can be about 17.5 degrees.

[0039] Geometric profiles of each spray hole may vary. In some examples, an inlet opening diameter 218 of the one or more spray holes can be greater than an outlet opening diameter 220 of the one or more spray holes while in other examples, the inlet opening diameter 218 of the one or more spray holes is about equal to the outlet opening diameter 220 of the one or more spray holes. It is contemplated that in some examples, the inlet opening diameter 218 of the one or more spray holes can be smaller than the outlet opening diameter 220 of the one or more spray holes. In addition, the cross-section of each spray hole 42 may vary across examples such that, in an example, the cross-sectional shape of the spray hole 42 can be any shape (regular or irregular) such as circular or polygonal. In addition, the cross-section along a length of the spray hole 42 may vary, e.g., in width or diameter. In some examples, the spray hole 42 can resemble a venturi along its length.

[0040] To adjust the amount of fuel delivered to a combustion chamber, it is common to design the diameter of the valve seat 28 to be larger. As noted prior, the fuel injector nozzle 200 can include a valve seat 28 positioned at the injector cavity distal end 14b. Increasing the seat angle 68, therefore, results in a larger valve seat 28 and fuel flow surface 29. In examples of the present disclosure, a seat angle 68 of the valve seat 28 can be between about 60 degrees and about 90 degrees. For instance, in an example, the seat angle 68 can be about 75 degrees. In another example, the seat angle 68 can be about 90 degrees. The result is an increased amount of fuel in the sac 60 when the needle valve 16 is in the open position and, by extension, an increased amount of fuel in the combustion chamber. Under these circumstances, while increased engine performance can be achieved, cavitation in the sac 60 can result if the sac 60 is not also modified.

[0041] According to examples of the present disclosure, methods of supplying and routing fuel (e.g., through a fuel injector, such as the fuel injector 10) are disclosed. FIG. 3 shows a flowchart of a method 300 of operating an engine, according to principles of the present disclosure. At step 302, the method 300 can include supplying a fuel past a needle valve configured to reciprocally move along a central axis within an injector cavity between an open

and a closed position. The injector cavity can be formed within a fuel injector nozzle. At step 304, the method 300 can include routing the fuel into a diverged portion of a sac, which extends from the injector cavity, when the needle valve is in an open position. At step 306, the method 300 can include routing the fuel into a converged portion of the sac, which extends from the diverged portion. Each of the diverged portion and the converged portion can define a sac volume of the sac. At step 308, the method 300 can include routing the fuel through one or more spray holes that extend from an inlet opening at the sac volume to an outlet opening. The inlet opening can be positioned within the sac to reduce cavitation caused by vapor collapse at the sac.

[0042] Examples of the method 300 can incorporate several (e.g., all) of the principles of the present disclosure discussed above. For example, in examples of the method 300, either a portion or an entirety of the inlet opening can be positioned at the diverged portion of the sac. In examples of the method 300, the fuel injector nozzle can include a valve seat positioned at an injector cavity distal end. In some such examples, a seat angle of the valve seat can be between about 60 degrees and about 90 degrees. In examples of the method 300, the one or more spray holes can have a plurality of spray holes. The inlet opening of one or more spray holes in the plurality of spray holes can be positioned at the diverged portion of the sac.

[0043] It is well understood that methods that include one or more steps, the order listed is not a limitation of the claim unless there are explicit or implicit statements to the contrary in the specification or claim itself. It is also well settled that the illustrated methods are just some examples of many examples disclosed, and certain steps can be added or omitted without departing from the scope of this disclosure. Such steps can include incorporating devices, systems, or methods or components thereof as well as what is well understood, routine, and conventional in the art.

[0044] The connecting lines shown in the various figures contained herein are intended to represent exemplary functional relationships and/or physical couplings between the various elements. It should be noted that many alternative or additional functional relationships or physical connections can be present in a practical system. However, the benefits, advantages, solutions to problems, and any elements that can cause any benefit, advantage, or solution to occur or become more pronounced are not to be construed as critical, required, or essential

features or elements. The scope is accordingly to be limited by nothing other than the appended claims, in which reference to an element in the singular is not intended to mean “one and only one” unless explicitly so stated, but rather “one or more.” Moreover, where a phrase similar to “at least one of A, B, or C” is used in the claims, it is intended that the phrase be interpreted to mean that A alone can be present in an embodiment, B alone can be present in an embodiment, C alone can be present in an embodiment, or that any combination of the elements A, B or C can be present in a single embodiment; for example, A and B, A and C, B and C, or A and B and C.

[0045] In the detailed description herein, references to “one embodiment,” “an embodiment,” “an example embodiment,” etc., indicate that the embodiment described can include a particular feature, structure, or characteristic, but every embodiment can not necessarily include the particular feature, structure, or characteristic. Moreover, such phrases are not necessarily referring to the same embodiment. Further, when a particular feature, structure, or characteristic is described in connection with an embodiment, it is submitted that it is within the knowledge of one skilled in the art with the benefit of the present disclosure to affect such feature, structure, or characteristic in connection with other embodiments whether or not explicitly described. After reading the description, it will be apparent to one skilled in the relevant art(s) how to implement the disclosure in alternative embodiments.

[0046] Furthermore, no element, component, or method step in the present disclosure is intended to be dedicated to the public regardless of whether the element, component, or method step is explicitly recited in the claims. No claim element herein is to be construed under the provisions of 35 U.S.C. 112(f), unless the element is expressly recited using the phrase “means for.” As used herein, the terms “comprises,” “comprising,” or any other variation thereof, are intended to cover a non-exclusive inclusion, such that a process, method, article, or apparatus that comprises a list of elements does not include only those elements but can include other elements not expressly listed or inherent to such process, method, article, or apparatus

[0047] While the present disclosure has been described as having an exemplary design, the present invention can be further modified within the spirit and scope of this disclosure. This application is therefore intended to cover any variations, uses, or adaptations of the invention using its general principles. Further, this application is intended to cover such departures from

the present disclosure as come within known or customary practices in the art to which this invention pertains.

CLAIMS

What is claimed is:

1. A fuel injector nozzle, comprising:
an injector cavity;
a sac that extends from an injector cavity distal end, the sac includes a sac volume defined by a diverged portion that extends from the injector cavity distal end and a converged portion that extends from the diverged portion; and
one or more spray holes that extend from an inlet opening at the sac volume to an outlet opening, the inlet opening positioned within the sac to reduce cavitation caused by vapor collapse at the sac.
2. The fuel injector nozzle of claim 1, wherein a portion of the inlet opening is positioned at the diverged portion of the sac.
3. The fuel injector nozzle of claim 2, wherein an entirety of the inlet opening is positioned at the diverged portion of the sac.
4. The fuel injector nozzle as in any one of claims 1-3, wherein the one or more spray holes has a plurality of spray holes, and wherein the inlet opening of one or more spray holes in the plurality of spray holes is positioned at the diverged portion of the sac.
5. The fuel injector nozzle as in any one of claims 1-4, wherein the inlet opening is positioned about halfway between a sac proximal end and a sac distal end.
6. The fuel injector nozzle as in any one of claims 1-5, wherein a vertical cross section of the sac is pear shaped.
7. The fuel injector nozzle as in any one of claims 1-6, further comprising a valve seat positioned at the injector cavity distal end, wherein a seat angle of the valve seat is between about 60 degrees and about 90 degrees.

8. The fuel injector nozzle of claim 7, wherein the seat angle is about 75 degrees.
9. The fuel injector nozzle of claim 7, wherein the seat angle is about 90 degrees.
10. The fuel injector nozzle as in any one of claims 1-9, wherein an inlet opening diameter of the one or more spray holes is greater than an outlet opening diameter of the one or more spray holes.
11. The fuel injector nozzle as in any one of claims 1-10, wherein each spray hole in the one or more spray holes has a spray hole angle between about 13 degrees and 22 degrees.
12. A fuel injector comprising:
 - a needle valve that has a needle valve tip and is configured to reciprocally move along a central axis between an open position and a closed position; and
 - a fuel injector nozzle including:
 - an injector cavity configured to receive the needle valve and that has a seat, which engages the needle valve tip when the needle valve is in the closed position, and
 - an injector cavity distal end;
 - a sac that extends from the injector cavity distal end, the sac includes a sac volume defined by a diverged portion that extends from the injector cavity distal end and a converged portion that extends from the diverged portion; and
 - one or more spray holes that extend from an inlet opening at the sac volume to an outlet opening, the inlet opening positioned within the sac to reduce cavitation caused by vapor collapse at the sac.
13. The fuel injector of claim 12, wherein either a portion or an entirety of the inlet opening is positioned at the diverged portion of the sac.
14. The fuel injector as in one of claims 12 or 13, further comprising a valve seat positioned at the injector cavity distal end, wherein a seat angle of the valve seat is between about 60

degrees and about 90 degrees.

15. The fuel injector of claim 14, wherein the seat angle is between about 75 degrees and about 90 degrees.

16. The fuel injector as in any one of claims 12-15, wherein the one or more spray holes has a plurality of spray holes, and wherein the inlet opening of one or more spray holes in the plurality of spray holes is positioned at the diverged portion of the sac.

17. A method, comprising:

supplying a fuel past a needle valve configured to reciprocally move along a central axis within an injector cavity between an opened and a closed position, the injector cavity formed within a fuel injector nozzle;

routing the fuel into a diverged portion, which extends from the injector cavity, of a sac when the needle valve is in an opened position;

routing the fuel into a converged portion, which extends from the diverged portion, of the sac extending from the diverged portion, each of the diverged portion and the converged portion defining a sac volume; and

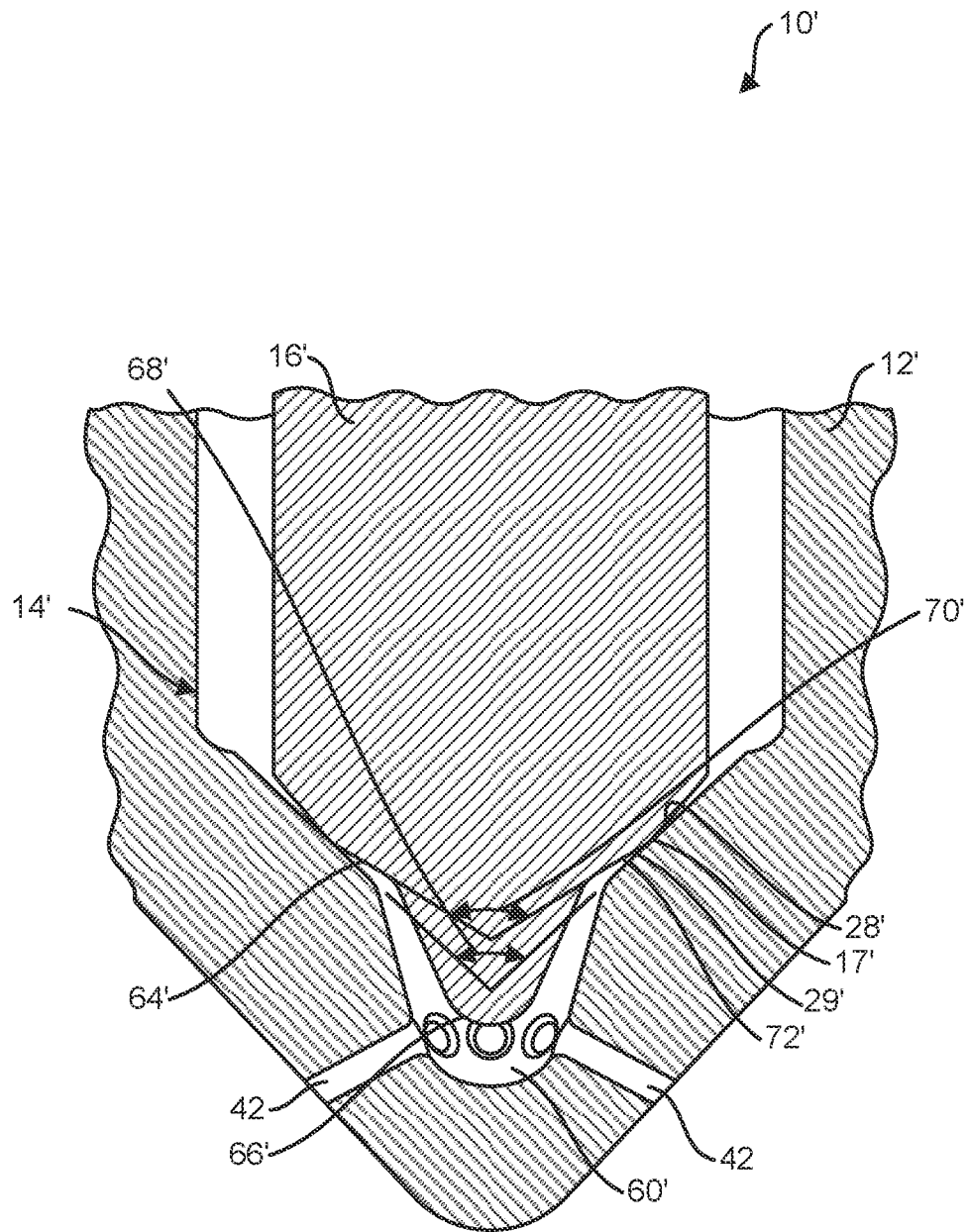
routing the fuel through one or more spray holes that extend from an inlet opening at the sac volume to an outlet opening, the inlet opening positioned within the sac to reduce cavitation caused by vapor collapse at the sac.

18. The method of claim 17, wherein either a portion or an entirety of the inlet opening is positioned at the diverged portion of the sac.

19. The method as in one of claims 17 or 18, wherein the fuel injector nozzle further comprises a valve seat positioned at an injector cavity distal end, wherein a seat angle of the valve seat is between about 60 degrees and about 90 degrees.

20. The method as in any one of claims 17-19, wherein the one or more spray holes has a plurality of spray holes, and wherein the inlet opening of one or more spray holes in the plurality

of spray holes is positioned at the diverged portion of the sac.



-- PRIOR ART --

FIG. 1

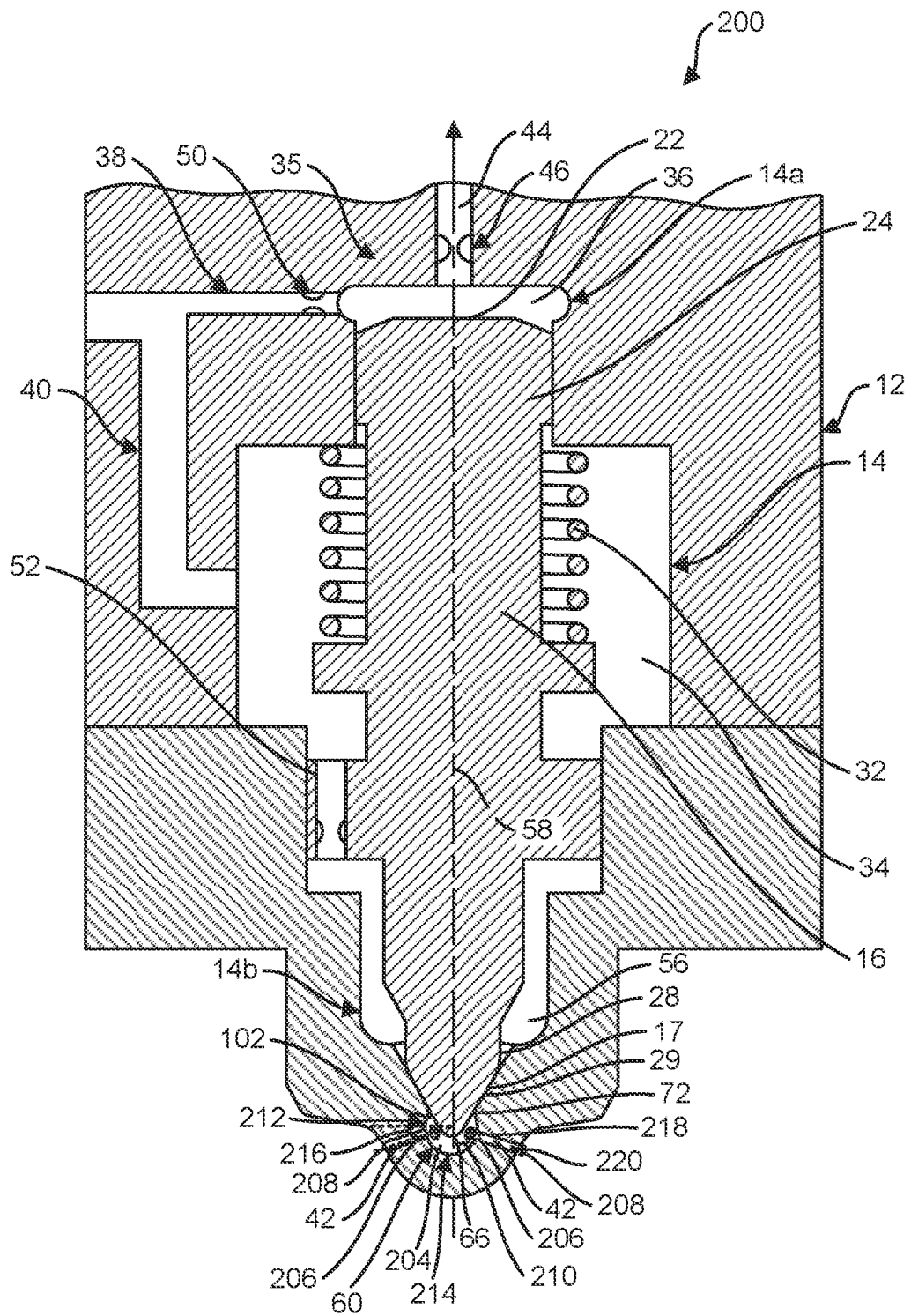


FIG. 2A

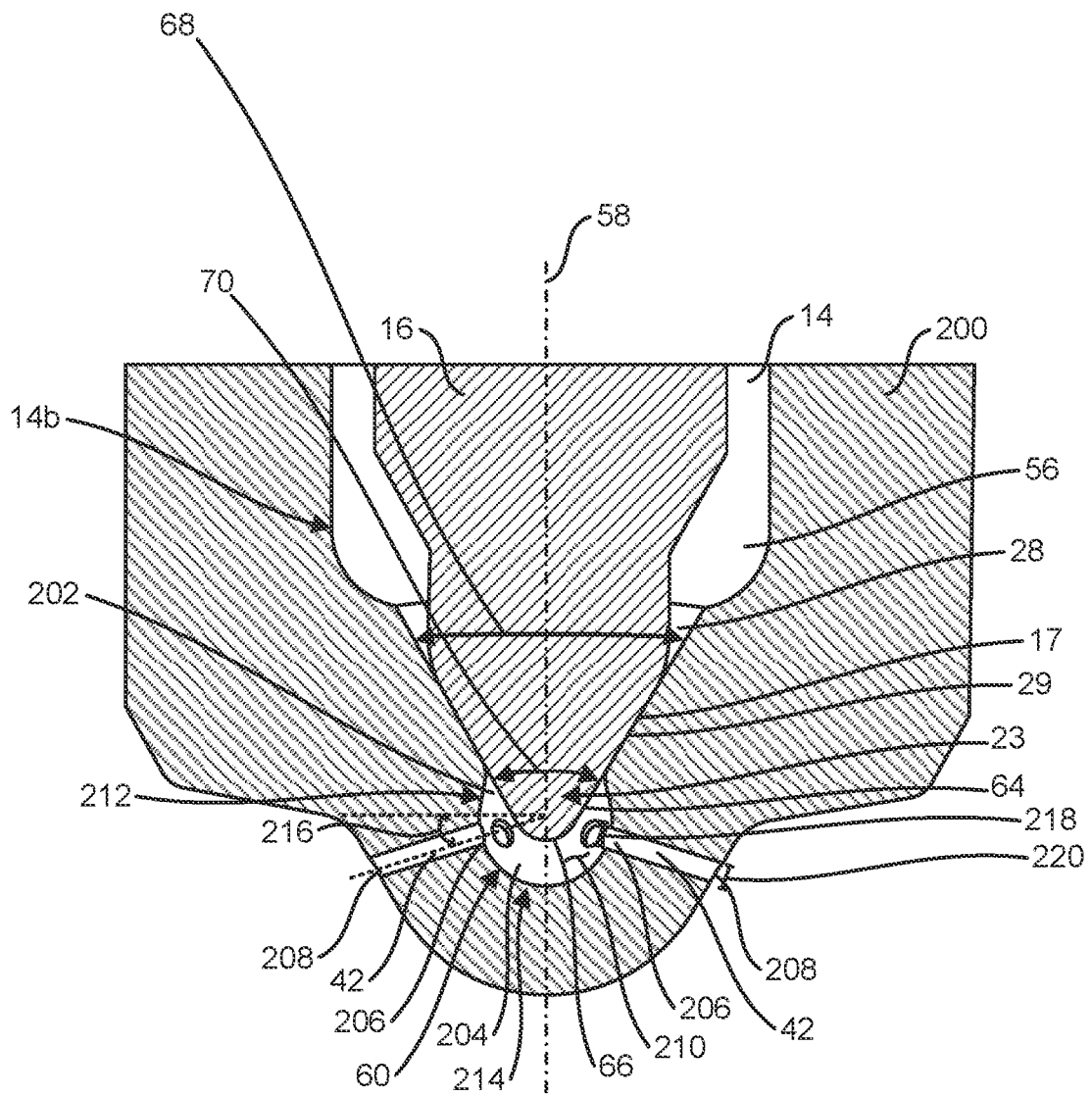
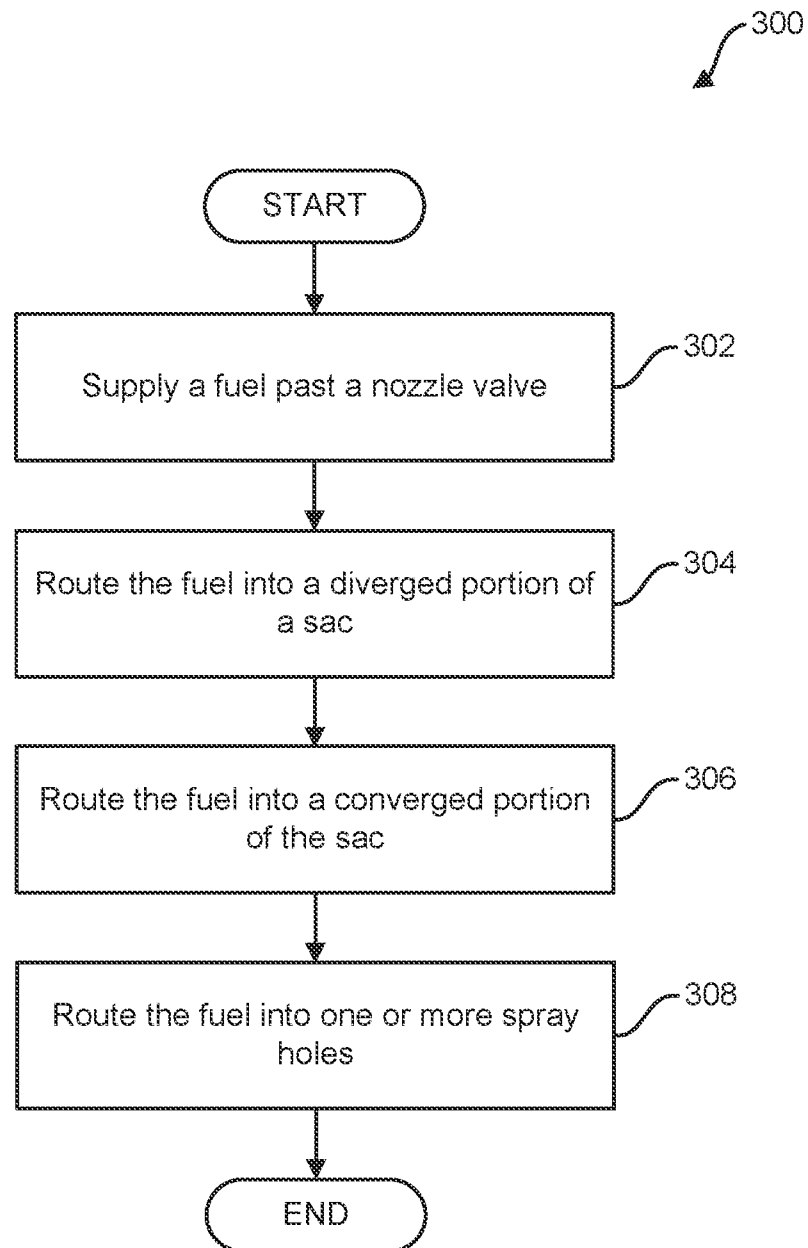


FIG. 2B

**FIG. 3**

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2022/011605

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - F02M 61/18; F02M 61/06; F02M 61/10; F02M 61/16 (2022.01)

CPC - F02M 61/1833; F02M 61/1806; F02M 61/182; F02M 61/1873; F02M 61/188; F02M 61/1893 (2022.02)

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)

see Search History document

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

see Search History document

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

see Search History document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	FR 456.230 A (SOCIÉTÉ SCHNEIDER & CIE) 20 August 1913 (20.08.1913) see machine translation and page 6 of ISA/237.	1-4, 12-15, 17-19
A	US 2018/0363614 A1 (CATERPILLAR INC.) 20 December 2018 (20.12.2018) entire document	1-4, 12-15, 17-19
A	US 2013/0048758 A1 (OMAE) 28 February 2013 (28.02.2013) entire document	1-4, 12-15, 17-19

☐ Further documents are listed in the continuation of Box C.☐ See patent family annex.

* Special categories of cited documents:

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

"D" document cited by the applicant in the international application

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

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

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search

10 March 2022

Date of mailing of the international search report

MAR 24 2022

Name and mailing address of the ISA/US

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Authorized officer

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2022/011605

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☒ Claims Nos.: 5-11, 16, 20
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☐ No protest accompanied the payment of additional search fees.