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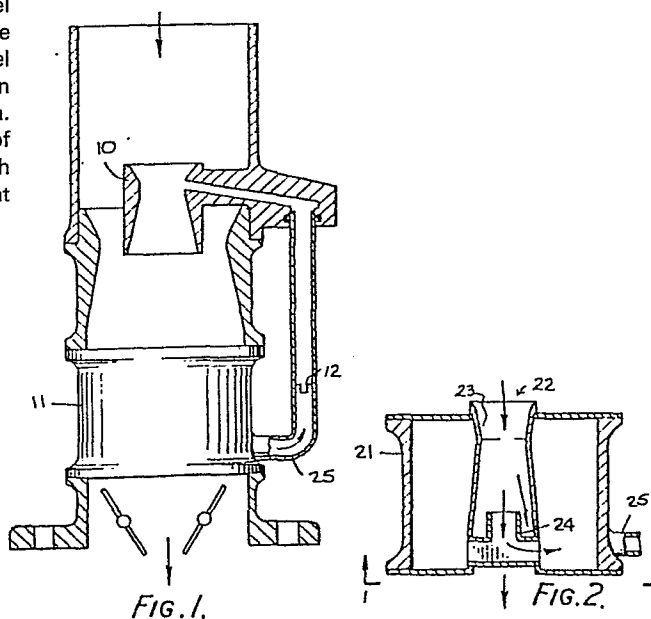
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(54) **Apparatus and methods for separating particles from a fluid stream using an inertial effect.**

(57) To reduce the average size of fuel particles in the air-fuel mixture supplied to an internal combustion engine, particle separating means (11) are provided in the path of the air fuel mixture for removing oversize fuel particles which are then returned either to the carburetor or to the fuel supply system. The particle separating means (11) may comprise an array of elements each comprising a venturi-shaped housing (22) with a trap (24) aligned with, but disposed downstream of, the throat (23) of the tube, or an array of vortex tubes (41).



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APPARATUS AND METHODS FOR SEPARATING PARTICLES

The present invention relates to apparatus and methods for separating particles, particularly but not exclusively for removing oversize fuel droplets in the fuel-air mixture for an internal combustion engine.

5 The desirability of uniform, small fuel droplets for internal combustion engines is well-documented. Combustion efficiency is improved as is distribution, permitting operation at leaner mixtures and increased compression ratio, with consequent decrease in fuel
10 consumption. Approaches to reduce fuel particle size have included vaporization techniques, multiple venturi carburetors, sonic venturis, and ultrasonic devices. All of these approaches have one or more of the following disadvantages: lowered volumetric efficiency, low cost
15 effectiveness, high pressure drop, large size, high power consumption, wear, complexity, and high start-up emissions. Further, these methods have in common the additional atomization or vaporization of fuel particles - the functions normally relegated to the carburetor or fuel
20 injector. In this invention, the oversize fuel particles, instead of being further atomized, are separated from the air-fuel mixture and returned to the fuel supply system for re-injection and atomization by the carburetor or fuel injector.

25 The fuel size distribution from a carburetor or

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injection nozzle covers a wide range and could range to about 200 micron. A finer distribution is desirable and a range extending to about 20 micron is both preferable and achievable, although any substantial reduction in fuel particle size is desirable. Removing the particles above a pre-determined size would result in improved air/fuel distribution, improved combustion, and reduced emissions. This invention describes, in an engine system, method and means by which the oversize fuel particles are separated using a particle separator, and returned to the fuel supply system or carburetor.

In a normally aspirated engine, the scavenge flow which carries the oversize fuel particles is at a pressure lower than atmospheric and consequently the scavenge flow must be pumped back to the fuel supply system or led to a lower pressure section such as the carburetor throat. In a turbocharged engine, wherein the manifold which contains the particle separator is pressurized, the scavenge flow can be returned, without pumping, to the fuel supply system, through a suitable metering valve.

One type of particle separator that can be utilized in the separation of fuel particles has been described in U.S. Pat. No. 3,725,271. Tests conducted by the Department of the Navy, and documented in Report NAVSECPHILADIV PROJECT T-454, Gas Turbine Combustion Air Salt Aerosol Separator Program, Subproject S-4617X, Task 10500S, show this type of separator to have the highest effectiveness at the lowest pressure drop among all the inertial separators tested in the particle range of 4 to 13 micron, an important range for engine fuel particles. The performance of this separator on salt water spray, as tested by the Department of the Navy, is as follows:

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Air Velocity - Feet Per Second	Efficiency - % Removed by Weight	Pressure Drop Inches of H ₂ O
17.5	73	--
35	90	1.5

5 According to one aspect of the invention there is provided a method of reducing the average fuel particle size of an air-fuel mixture comprising the steps of:

 a. producing a flow of the air-fuel mixture by mixing air from an air supply system and fuel from a fuel
10 supply system;

 b. inducing the flow into an inertial separator;

 c. removing the fuel particles greater than a pre-determined size within the separator; and

 d. returning the fuel particles greater than a
15 pre-determined size to the fuel supply system.

 According to another aspect of the invention there is provided apparatus for reducing the average fuel particle size in an air-fuel mixture for a spark-ignition engine comprising inertial means for separating a portion
20 of the air-fuel mixture containing fuel particles greater than a pre-determined size prior to its introduction to the cylinders of the engine, and means for returning the separated portion to the fuel supply system of the engine.

 In one embodiment of the invention, the means
25 for separating the oversize fuel particles comprises an array of venturi nozzles each fitted with a central trap downstream of the throat into which the oversize particles are inertially urged, together with a small amount of scavenge air. In addition, means may be provided to re-
30 circulate the oversize particles to a reduced pressure zone such as the carburetor throat for re-atomization, with means for metering the re-circulated flow.

 Alternatively, means may be provided to return the over-size particles to the fuel supply system, for example via
35 a fuel storage chamber, which is maintained at a reduced

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pressure, and a fuel pump activated by a level sensor, or via a pump only.

In another embodiment of the invention, the means for separating the oversize fuel particles comprises
5 an array of vortex tubes through which the air-fuel mixture flows, the oversize fuel particles being centrifuged outwards and re-circulated to the carburetor or the fuel supply system as described above.

In another embodiment of the invention, the means
10 for separating the oversize fuel particles comprises a vortex separator including an array of vanes or louvered slots disposed forward of the leading edge of the main air discharge tube.

In another embodiment of the invention, the means
15 for separating the oversize fuel particles consists of concentric tubular or rectangular members which cause the main air flow to undulate and separate from the particles which are scavenged out together with a small amount of scavenge air.

20 According to a further aspect of the invention, there is provided a vortex particle separator comprising, in combination, a housing having an inlet and an outlet arranged for flow therethrough of air carrying particles of different weights and, disposed in the housing across
25 the line of air flow from the inlet to the outlet, an array of elements each having a substantially straight inlet tubular body with a cylindrical central passage therethrough and an inlet and an outlet at opposite ends, deflectors adjacent the inlet for creating a vortex
30 stream in the inlet air to concentrate heavier particles in the air at the periphery of the passage and provide a main core of air at the center of the passage containing lighter particles, and an outlet member having a central core air passage communicating with the cylindrical
35 central passage of the tubular body and disposed within

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the passage at the outlet, the exterior wall of the outlet member defining a generally annular containment scavenge passage for heavy particle outlet within the cylindrical central passage of the tubular body through
5 which pass the heavier particles, while main core air at the center of the passage passes through the central core of air passage of the outlet member, and an array of turning vanes disposed upstream of the leading edge of the outlet member to cause that portion of the main
10 core air which normally turns radially inward to the outlet member to negotiate a sharp turn radially inward into said vanes consequently depositing more of the heavier particles to the heavy particle outlet defined by said annular containment scavenge passage.

15 According to yet a further aspect of the invention, there is provided a particle separator comprising, in combination, a housing having an inlet and an outlet arranged for flow therethrough of air carrying particles of different weights; and, disposed in the
20 housing across the line of air flow from the inlet to the outlet, an array of elements each having a tubular body of converging-diverging shape, the minimum through passage of which defines a throat, the said tubular body having an outlet adapted to be connected to a manifold;
25 a tubular particle trap disposed substantially along the longitudinal axis of said tubular body and downstream of said throat leading to the manifold, said trap converging to a smaller diameter; a tubular member surrounding outside of said trap, the inlet of said surrounding
30 tubular member being disposed downstream of the point where said trap starts to converge, thereby forming two annuli, the first annulus formed between said tubular member and said trap, causing the main airstream to make a relatively sharp turn into the first annulus thereby
35 depositing heavier particles to the outer second annulus

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formed by said tubular body and said member, the outlet of the second annulus communicating with the manifold.

Embodiments according to the invention will now be described, by way of example only, with reference
5 to the accompanying drawings, in which:

Figure 1 is a diagrammatic view of an embodiment of a combined particle separator and engine throttle body incorporated in the engine inlet and carburetor system;

10 Figure 2 is a vertical section through one embodiment of a particle separator, showing one only, for clarity, of an array of elements, each having a venturi nozzle with a central trap downstream of the throat and a scavenge tube leading away and to a carburetor throat
15 as shown in Figure 1 or to a fuel supply system as shown in Figure 9;

Figure 3 is an elevational view of Figure 2, taken along the line 1-1;

Figure 4 is a vertical section through another
20 embodiment of a particle separator showing one of an array of elements, each comprising a vortex tube, a plurality of vanes or louvered slots disposed forward of the leading edge of the main air discharge tube, and a scavenge tube leading away and to a carburetor throat as
25 shown in Figure 1 or to a fuel supply system as shown in Figure 9;

Figure 5 is a vertical section through another embodiment of a particle separator showing one of an array of elements, each comprising a concentric tube with
30 a particle trap leading to a scavenge outlet and a second particle trap leading to the same scavenge outlet;

Figure 6 is a perspective view of the element of Figure 5;

Figure 7 is a vertical section through an
35 element of another embodiment of a particle separator

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similar to that of Figure 5 but in which the portions forming the trap and diffuser are substantially rectangular, rather than circular;

Figure 8 is an elevational view taken on line 2-2 of Figure 7 showing the outlet of the substantially rectangular arrangement of Figure 7; and

Figure 9 is a diagrammatic view of another embodiment of a combined particle separator and engine throttle body incorporated in the engine inlet and downstream of a fuel injector nozzle, and showing the oversize fuel particles being returned to the fuel supply system via a fuel collecting chamber, maintained at reduced pressure, and a pump, or, alternatively, the oversize fuel particles being returned to the fuel supply system via a pump only.

Referring to Figures 1 and 2, the air-fuel mixture from the carburetor throat 10 enters the separating device 11, which is made up of elements such as either 21 of Figure 2, 46 of Figure 4, 59 of Figure 5, or 71 of Figure 7, sections of which are shown in Figure 2, Figure 4, Figure 5 and Figure 7. Referring to Figure 2, particles are quickly accelerated at the inlet section 22 to almost air velocity. Particle inertia of the larger particles causes them to leave the streamline at the throat 23 and then enter the trap 24. The oversize particles or particles greater than a predetermined size are then re-circulated with a small amount of scavenge air through tube 25 to the carburetor throat 10 for re-atomization. Test data for this type of separator have shown that most of the dynamic head is recovered downstream so that the scavenge pressure is higher than the static pressure in the carburetor throat and consequently re-circulation can occur. Since the separating effectiveness increases with increased velocity through the separator a metering valve 12 is shown in the scavenge

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tube 25 which maintains essentially a constant scavenge flow so that the ratio of scavenge flow to primary air flow is reduced with increase in primary air flow. A reduction in this ratio reduces the separation effectiveness and compensates consequently for the increase in effectiveness as a result of increased velocity through the separator, thereby maintaining essentially a constant size of particles which is separated. The carburetor main metering jet is modified to accept the re-circulated flow.

Referring to Figures 2 and 3 an array of seven separator elements is shown to keep the height of the assembly as small as possible in keeping with maximum open area and minimum pressure loss.

The separating element shown in Figure 4 is a vortex tube 41. In this case an improvement is shown to a typical vortex tube to increase the separating effectiveness and reduce the pressure loss of the primary flow and secondary flow which is critical in the automotive application. The flow of air and particles is given a rotational flow by the deflectors 45. A vortex is generated causing the heavier particles to be centrifuged towards the outside diameter. Disposed upstream of the main air discharge tube 43 is shown a plurality of louvers or vanes 44. Since the discharge tube is about 50% of the area of the primary tube and since only about 10% scavenge flow is desired, a substantial amount of primary air must make an abrupt change in direction to enter the discharge tube. This increases the separation effectiveness but also increases the pressure loss. By placing turning vanes 44 in the area as shown, the mixing loss of the primary flow is reduced and consequently the overall pressure loss is reduced allowing operation at higher velocities and thereby higher separation effectiveness, or, conversely, lower velocities and reduced

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scavenge pressure loss for the same effectiveness. Also particle capture is enhanced by virtue of the particles having to traverse a shorter distance from vane to vane and, in so doing, are re-entrained in the next flow
5 streamline and re-accelerated so as to be able to negotiate the following vane gap and enter the capture zone.

Another separating element is shown in Figure 5, a perspective of which is shown in Figure 6. The air-fuel mixture enters this separator. Particles are quickly
10 accelerated at the inlet section 52 to almost air velocity. Particle inertia of the larger particles causes them to leave the streamline at the throat 53 and enter the trap 54. The main or primary air flow travels
15 through passages 55 and 56. Additional oversize particles are separated in the air streamline undulation between 55 and 56, these particles entering trap 57 which leads to a common manifold 58 with trap 54 and from there the particles are scavenged out through tube 25. The test
20 data on this concentric geometry have shown that practically 100% of all particles above a size as low as about 2 micron can be efficiently removed.

Another version of the element geometry of Figure 5 is shown in Figure 7 wherein the passages are
25 rectangular in cross-section, as shown by Figure 8, rather than tubular.

Referring to Figure 9 the separator 11, which could be of any of the configurations shown in Figures 2, 4, 5 or 7, is shown mounted to the throttle body 91, of
30 a single-point injection system engine inlet and downstream of a fuel injector 92. Air enters at 93 and mixes with the fuel, the air-fuel mixture entering the separator 11. The scavenge flow carrying the oversize particles travels through tube 94 to a fuel collecting chamber 95 which is
35 vented to a lower pressure zone, causing scavenge flow.

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The fuel in the air-fuel mixture in tube 94 is scrubbed out by the fuel 96 in the chamber 95. The level of the fuel 96 is maintained above the outlet of tube 94 by valve 97 and a level sensor which activates a fuel
5 scavenge pump 98 which returns the fuel to the fuel supply system. Alternatively, the oversize particles can be scavenged out directly to the fuel supply system via pump 99.

10 In a turbocharged engine, wherein the manifold containing the particle separator is pressurized to a higher pressure than the fuel supply system, then the scavenge flow containing the oversize fuel particles can be returned, without pumping, to the fuel supply system, through a suitable metering valve.

15 It will be appreciated that the particle separators described above may also be used for separating other particles than fuel droplets.

CLAIMS:

1. A method of reducing the average fuel particle size in an air-fuel mixture comprising the steps of:
 - a. producing a flow of the air-fuel mixture by mixing air from an air supply system and fuel from a fuel supply system;
 - b. inducing the flow into an inertial separator (11);
 - c. removing the fuel particles greater than a pre-determined size within the separator; and
 - d. returning the fuel particles greater than a pre-determined size to the fuel supply system.
2. Apparatus for reducing the average fuel particle size in an air-fuel mixture for a spark-ignition engine comprising inertial means (11) for separating a portion of the air-fuel mixture containing fuel particles greater than a pre-determined size prior to its introduction to the cylinders of the engine, and means for returning the separated portion to the fuel supply system of the engine.
3. Apparatus for reducing the fuel particle size in an air-fuel mixture for a spark ignition engine comprising inertial means (11) for separating a portion of the air-fuel mixture containing fuel particles greater than a pre-determined size prior to its introduction to the cylinders of the engine, and means for returning the separated portion to the fuel supply system of the engine, said separated portion being recirculated to a venturi portion (10) of the engine from an area of higher static pressure, wherein said inertial means (11) comprises a particle separator having an array of elements, each element having a venturi shaped housing and a centrally aligned trap (24) exposed downstream of the

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throat (23) into which the flow of fuel particles greater than a pre-determined size is inertially separated.

4. Apparatus according to either claim 2 or claim 3, wherein the inertial means (11) comprises a particle separator (11) disposed downstream of a carburetor (10) with a conduit (25) leading from the particle separator to the carburetor, the flow of fuel particles greater than a pre-determined size being re-circulated to the carburetor through said conduit (25).

5. Apparatus according to claim 4, wherein the conduit (25) contains a flow control valve (12) which reduces the flow through it in response to an increase in pressure drop across it.

6. Apparatus according to either claim 2 or claim 3, wherein the inertial means (11) comprises a particle separator disposed downstream of a pressurized carburetor (92), as in the case of a turbocharged engine, with a conduit (94) leading from the particle separator to the fuel supply system, the flow of fuel particles greater than a pre-determined size being returned to the fuel supply system of the engine through said conduit (94).

7. Apparatus according to either claim 2 or claim 3, wherein the inertial means comprises a particle separator (11) disposed downstream of a fuel injector nozzle (92) with a conduit (94) leading from the particle separator to a fuel collecting chamber (95), said chamber being evacuated to a low pressure zone, the flow of fuel particles greater than a pre-determined size being fed to said chamber (95) through said conduit (94) and returned from said chamber to the fuel supply system of the engine by suitable means.

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8. Apparatus according to either claim 2 or claim 3, wherein the inertial means comprises a particle separator (11) disposed downstream of a fuel injector nozzle (92) with a conduit (94) leading from the particle separator to a pump (98;99) and then to the fuel supply system of the engine, the flow of fuel particles greater than a pre-determined size being returned to the fuel supply system of the engine through said conduit (94).

9. Apparatus according to either claim 2 or claim 3, wherein the inertial means comprises a particle separator (11) disposed downstream of a fuel injector nozzle which discharges into a pressurized air chamber, as in the case of a turbocharged engine, with a conduit (94) leading from the particle separator to the fuel supply system of the engine, the flow of fuel particles greater than a pre-determined size being returned to the fuel supply system of the engine through said conduit.

10. Apparatus according to claim 2, wherein the inertial means comprises a particle separator having an array of elements, each element having a venturi-shaped housing (21) and a centrally aligned trap (24) disposed downstream of the throat (23) into which the flow of fuel particles greater than a pre-determined size is inertially separated.

11. Apparatus according to claim 2, wherein the inertial means comprises a particle separator consisting of an array of vortex tubes (41).

12. A vortex particle separator comprising, in combination, a housing having an inlet and an outlet arranged for flow therethrough of air carrying particles of different weights and, disposed in the housing across

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the line of air flow from the inlet to the outlet, an array of elements each having a substantially straight inlet tubular body (41) with a cylindrical central passage therethrough and an inlet and an outlet at opposite ends, deflectors (45) adjacent the inlet for creating a vortex stream in the inlet air to concentrate heavier particles in the air at the periphery of the passage and provide a main core of air at the center of the passage containing lighter particles, and an outlet member having a central core air passage (43) communicating with the cylindrical central passage of the tubular body and disposed within the passage at the outlet, the exterior wall of the outlet member defining a generally annular containment scavenge passage for heavy particle outlet within the cylindrical central passage of the tubular body through which pass the heavier particles, while main core air at the center of the passage passes through the central core of air passage (43) of the outlet member, and an array of turning vanes (44) disposed upstream of the leading edge of the outlet member to cause that portion of the main core air which normally turns radially inward to the outlet member to negotiate a sharp turn radially inward into said vanes consequently depositing more of the heavier particles to the heavy particle outlet defined by said annular containment scavenge passage.

13. A particle separator according to claim 12, wherein the array of turning vanes (44) are more or less u-shaped and oriented so that their inlets and outlets are substantially parallel to the longitudinal axis of the vortex particle separator.

14. A particle separator comprising, in combination, a housing having an inlet and an outlet arranged for flow therethrough of air carrying particles of different

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weights; and, disposed in the housing across the line of air flow from the inlet to the outlet, an array of elements each having a tubular body of converging-diverging shape, the minimum through passage of which defines a throat (53), the said tubular body having an outlet adapted to be connected to a manifold; a tubular particle trap (54) disposed substantially along the longitudinal axis of said tubular body and downstream of said throat leading to the manifold, said trap converging to a smaller diameter; a tubular member surrounding outside of said trap, the inlet of said surrounding tubular member being disposed downstream of the point where said trap starts to converge, thereby forming two annuli (56,57), the first annulus (56) formed between said tubular member and said trap, causing the main airstream to make a relatively sharp turn into the first annulus thereby depositing heavier particles to the outer second annulus (57) formed by said tubular body and said member, the outlet of the second annulus communicating with the manifold.

15. A particle separator according to claim 14, wherein said tubular body, said tubular particle trap and said tubular member have substantially rectangular cross-sections perpendicular to the direction of air flow.

16. A method of separating a substance of greater density from another substance of lesser density, wherein the substance of greater density is fuel and the substance of lesser density is air in an air-fuel mixture, comprising the steps of:

a. producing a flow of the air-fuel mixture by mixing air from an air supply system and fuel from a fuel supply system;

b. inducing a flow of the substances along a curvilinear path, the flow having a pre-determined stream

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portion therein, the stream portion adjacent the downstream end of the curvilinear path extending substantially adjacent a pre-determined line, the substance of greater density in response to the flow along the curvilinear path moving relative to the other substance in a direction extending away from the center of curvature of the curvilinear path and into the pre-determined stream portion;

c. decelerating the flow of the accelerated substances downstream of the curvilinear path by diffusing the flow of the substances, the flow of the substances being decelerated adjacent to the pre-determined line;

d. inducing a flow of the pre-determined stream portion along another curvilinear path, the flow having another pre-determined stream portion adjacent the downstream end of the other curvilinear path extending substantially adjacent to the pre-determined line, the substance of greater density in response to the flow along the other curvilinear path being adapted to move relative to the other substance in a direction extending away from the center of curvature of the other curvilinear path and into the other pre-determined stream portion;

e. decelerating the flow of the accelerated pre-determined stream portion downstream of the other curvilinear path by diffusing the flow of the substances, the flow of the substances being decelerated adjacent to the pre-determined line;

f. receiving and permanently segregating the other pre-determined stream portion of the flow containing the substance of greater density adjacent the pre-determined line from the remaining portion of the flow while the flow of the substances is being diffused; and

g. returning the pre-determined stream portion to the fuel supply system.

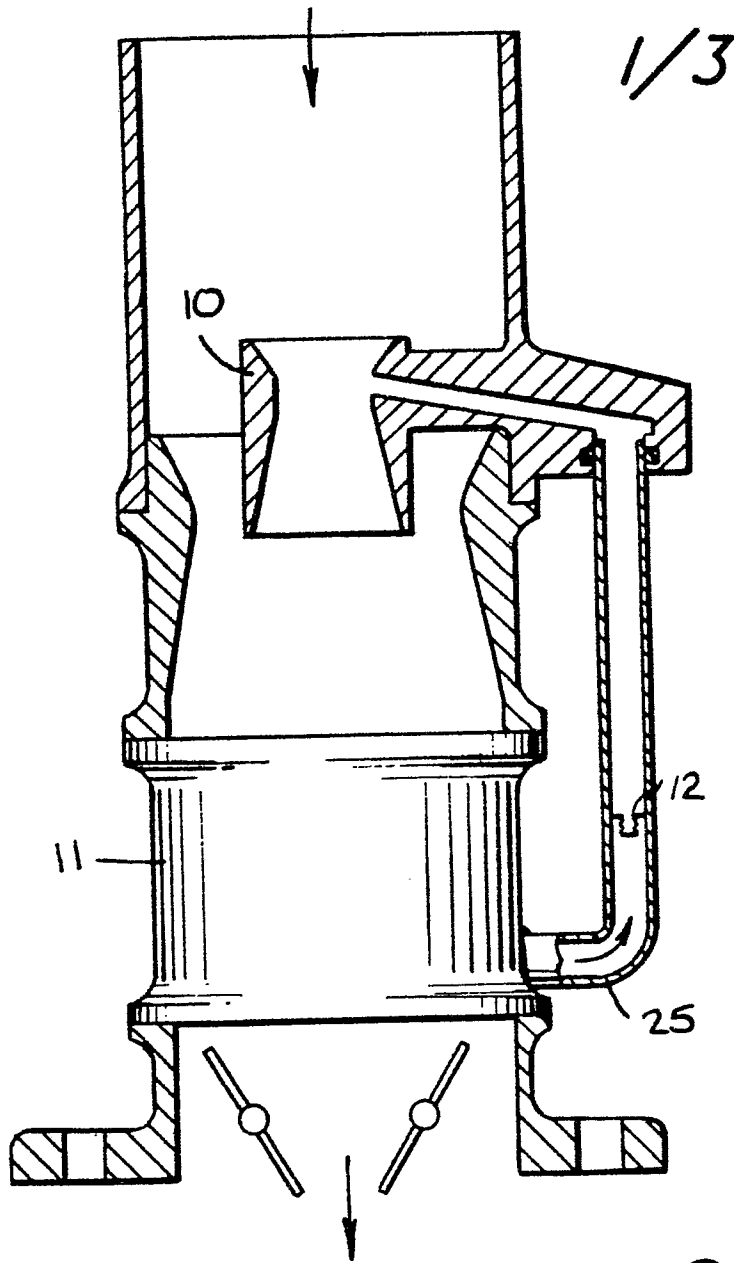


FIG. 1.

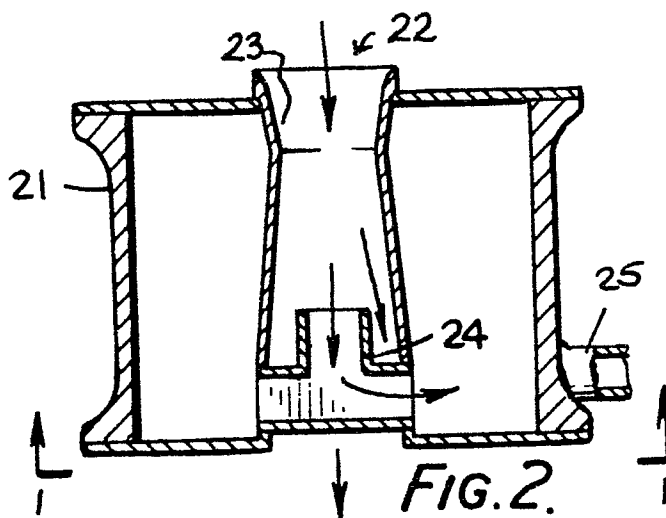


FIG. 2.

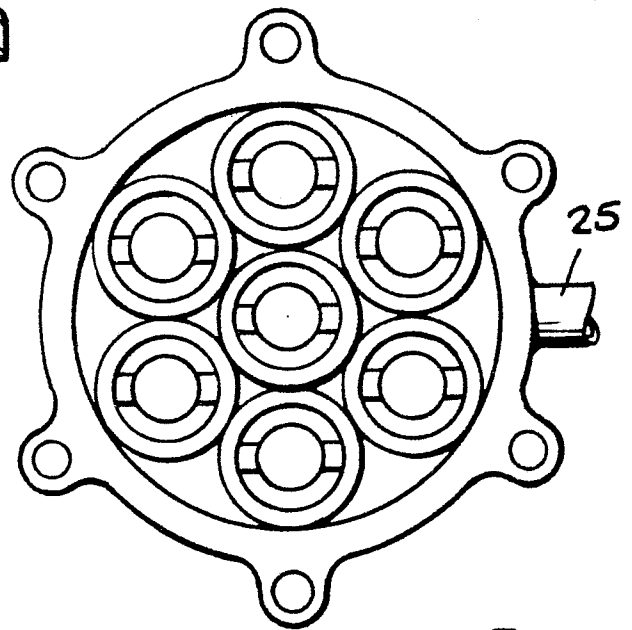


FIG. 3.

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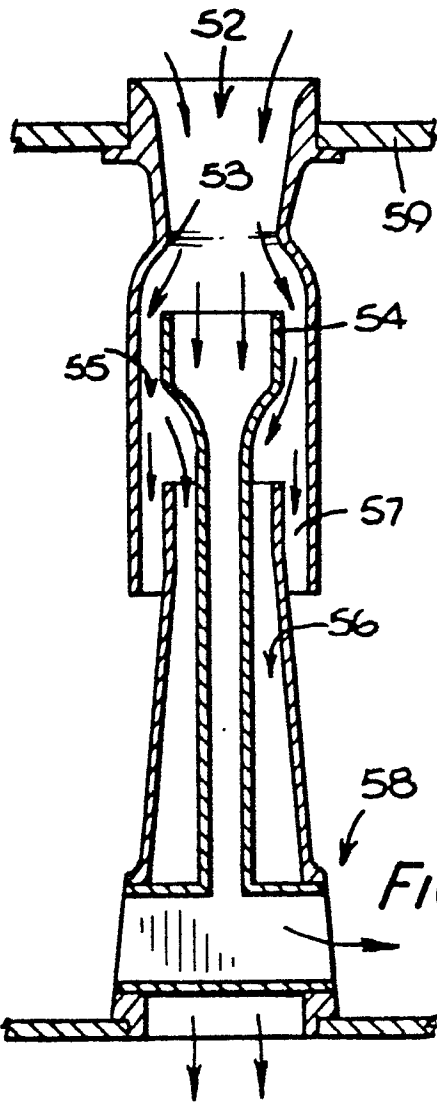


FIG. 5.

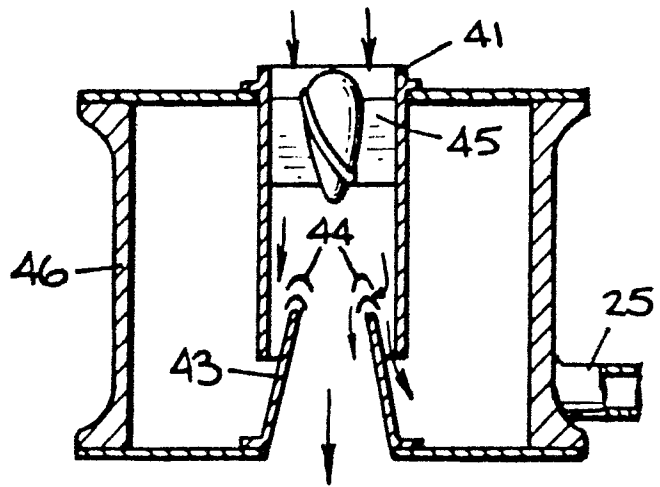


FIG. 4.

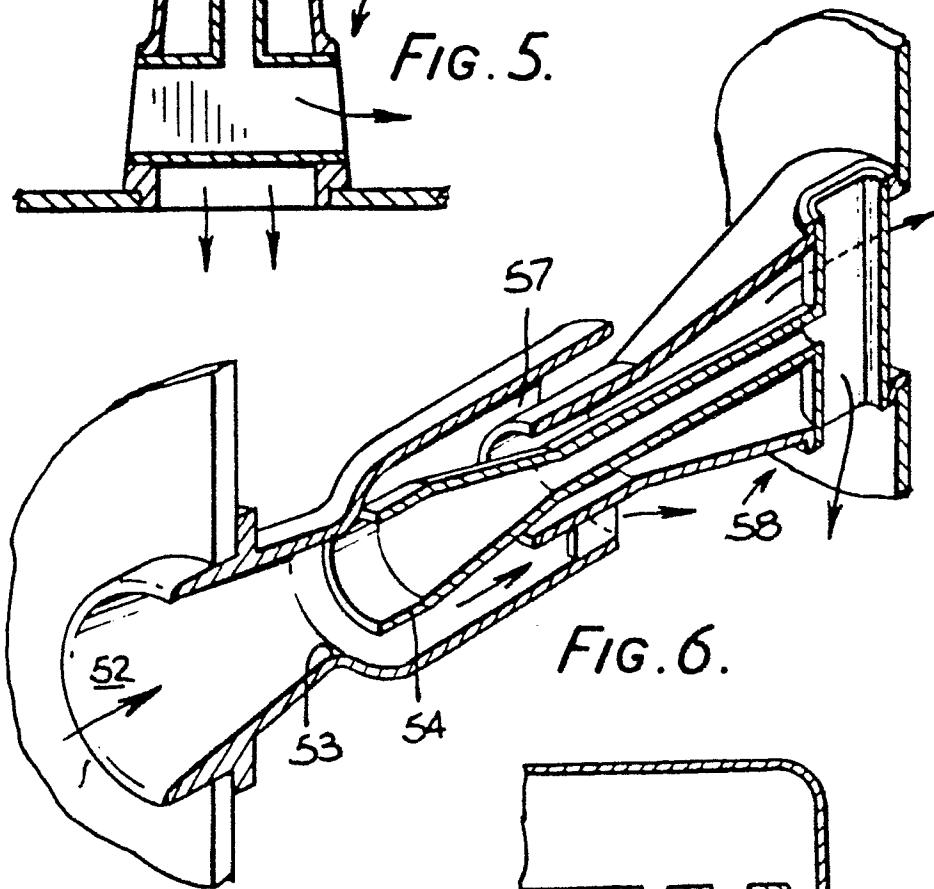


FIG. 6.

FIG. 8.

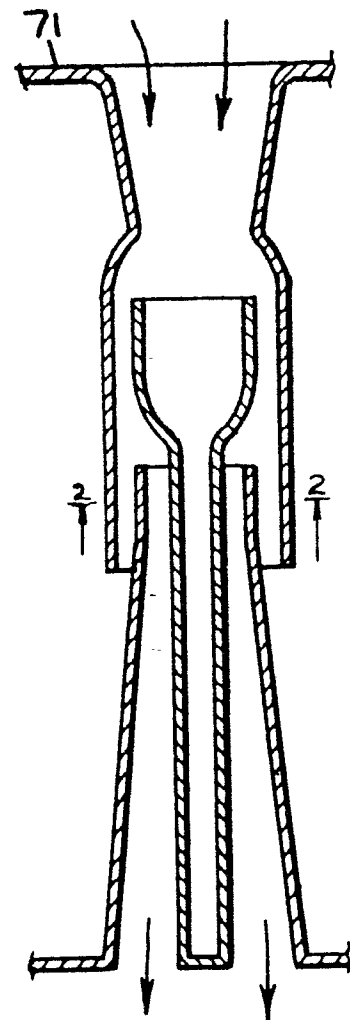
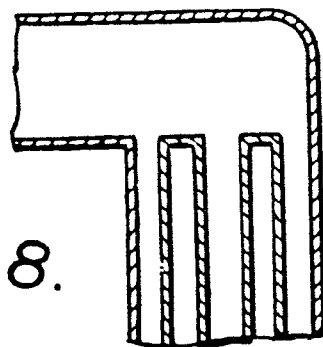
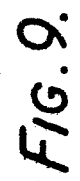


FIG. 7.





DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.4)
X	GB-A-1 214 991 (THE STANDARD-TRIUMPH MOTOR CO., LTD.) * Page 1, lines 9-43, 49-53, 62-70, 77-84, 90-95; page 2, lines 1, 2, 15-48, 105-124; page 3, lines 41-48, 85-130; page 4, lines 1-6 *	1, 2, 4 7, 8	F 02 M 33/02 B 01 D 45/04 B 01 D 45/16
X	DE-A-2 303 712 (MALHERBE) * Page 8, paragraph 2; pages 9-11; page 12, lines 1-4 *	1, 2, 4	
Y		3, 10, 16	
D, Y	US-A-3 725 271 (GIANNOTTI ASSOCIATES) * Abstract; column 1, lines 44-48; column 2, lines 14-68; column 3, lines 9-12; column 4, lines 16-68; column 5, lines 1-18; column 7, lines 1-18; claim 1 *	3, 10, 16	TECHNICAL FIELDS SEARCHED (Int. Cl.4) F 02 M B 01 D
A		14	
X	FR-A-2 287 588 (ELF-UNION) * Page 1, lines 1-13; page 2, lines 26-39; page 3, lines 1-4, 11-16, 21-23 *	1, 2, 4	
The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 14-01-1986	Examiner JORIS J.C.
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			



DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.4)
Y	---	11	
Y	US-A-3 884 658 (PALL CORP.) * Abstract; column 6, lines 33-68; column 7, lines 1-20; column 8, lines 18-35 *	11	
A	---	12	
A	FR-A-2 311 573 (LUCAS) * Page 1, lines 1-4; page 4, lines 13-37; page 5, lines 1,2; page 7, lines 4-19 *	15,16	
A	US-A-4 089 665 (BURVELL CANADA CO., LTD.) -----		
The present search report has been drawn up for all claims			TECHNICAL FIELDS SEARCHED (Int. Cl.4)
Place of search THE HAGUE		Date of completion of the search 14-01-1986	Examiner JORIS J.C.
CATEGORY OF CITED DOCUMENTS			
X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	