United States Patent

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[73] Assignee **the United States of America as represented by the Secretary of Agriculture**
Continuation-in-part of application Ser. No. 592,888, Nov. 8, 1966, now abandoned.

[54] **APPARATUS FOR REMOVING ENTRAINED PARTICLES FROM GASES**
8 Claims, 8 Drawing Figs.

[52] **U.S. Cl.** **55/399,** 55/448, 55/456, 55/459
[51] **Int. Cl.** **B01d 45/12**
[50] **Field of Search** 55/399, 448, 456, 459

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ABSTRACT: An apparatus for removing entrained particles from gases, of particular use as a spark arrester with internal combustion engines, comprises, essentially, an elongated cylinder, closed at one end and having a spiral member secured to the inner wall. Exhaust gases enter tangentially at a point near the open end and travel in a thin layer along a spiral path adjacent the wall toward the closed end. Near the closed end, the gases reverse direction and travel in an axial spiral path along the center of the cylinder and out the open end, while incandescent carbon particles continue by inertia in their original spiral path and are retained or pulverized by rubbing against the cylinder wall as they continue to circulate at the base of the cylinder. The absence of baffles minimizes back pressure on the engine.

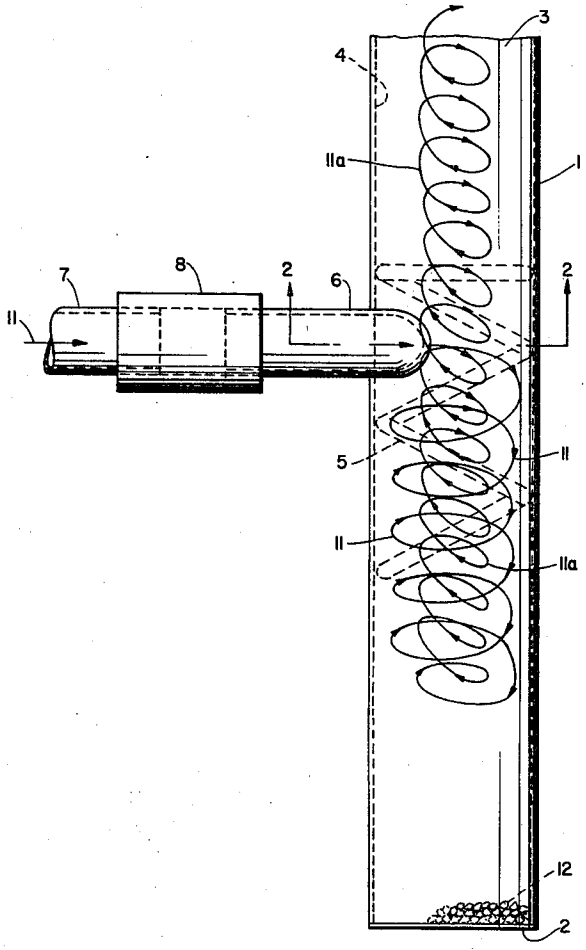


FIG. 1

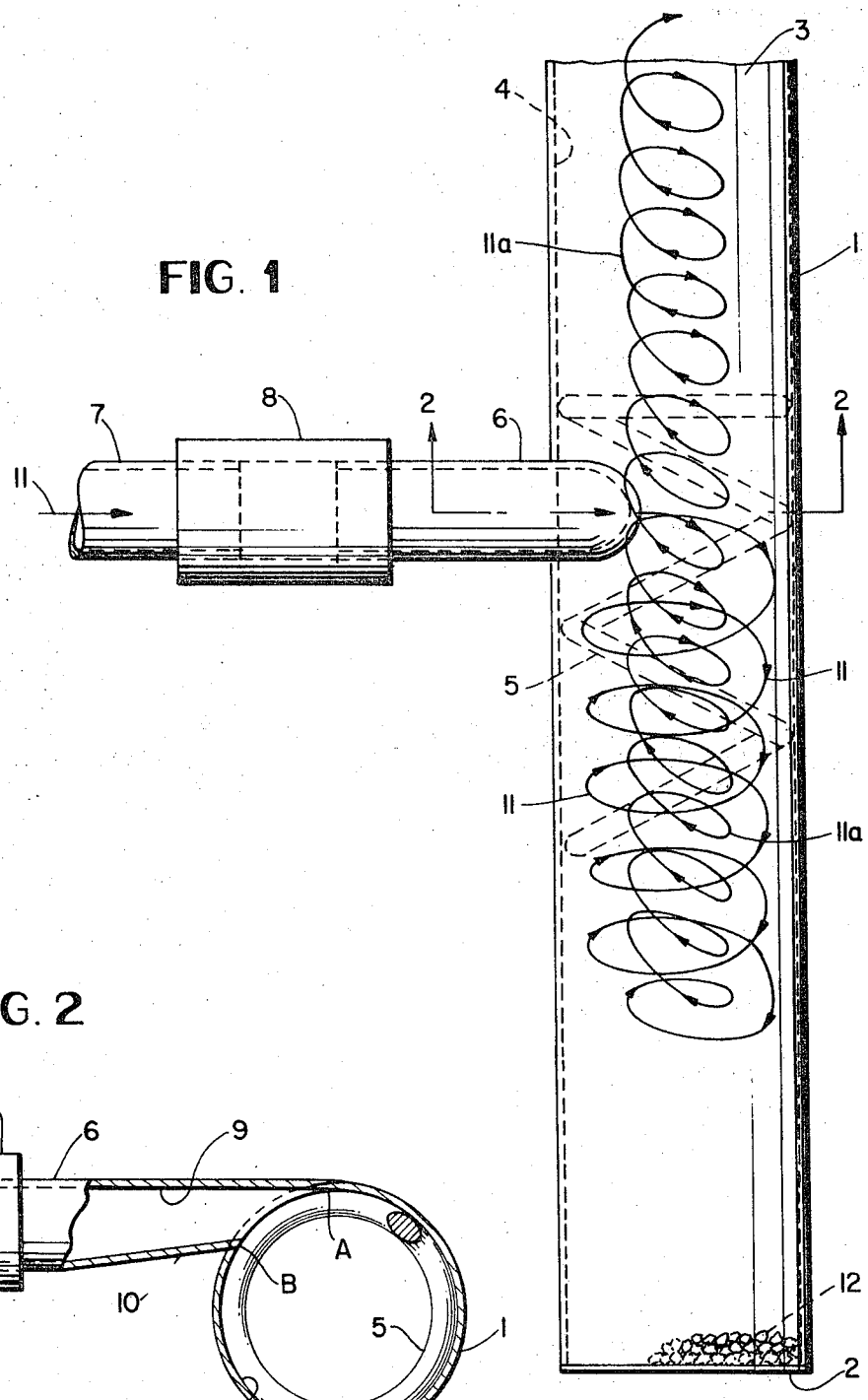


FIG. 2

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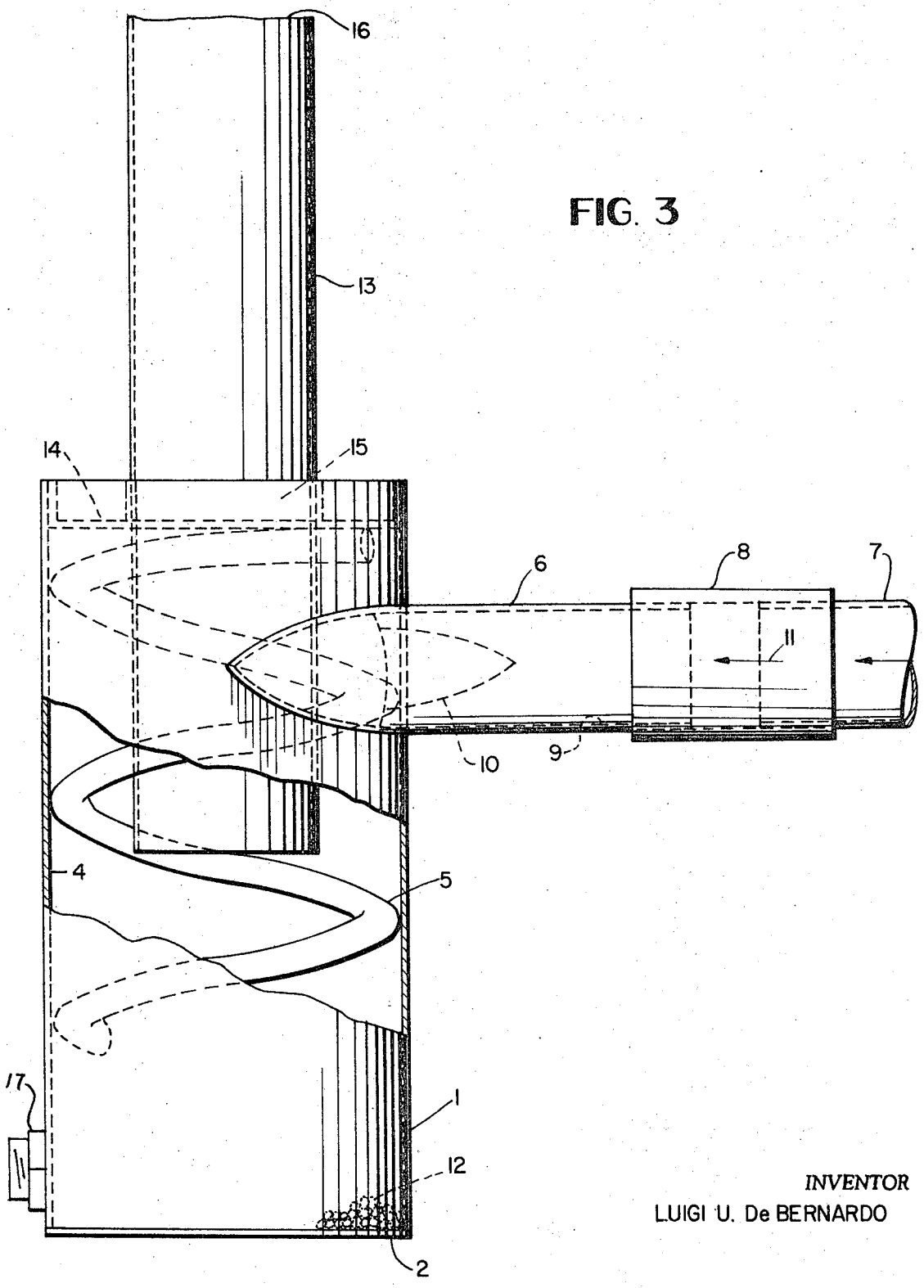


FIG. 3

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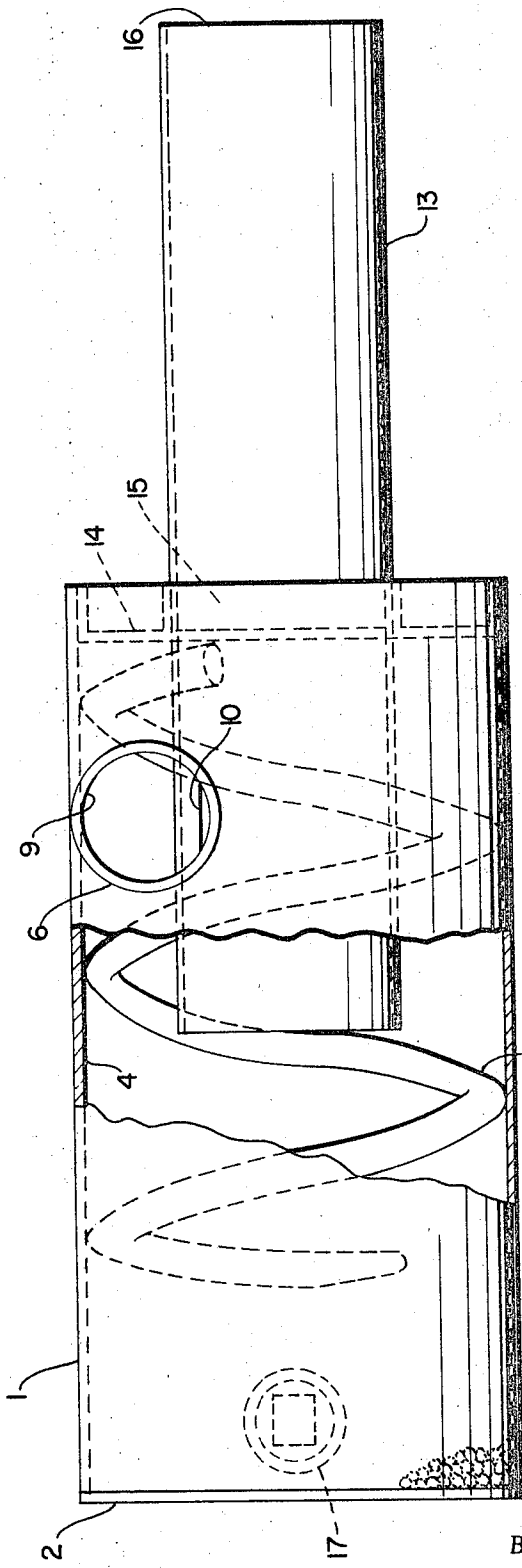


FIG. 4

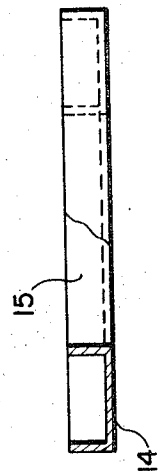


FIG. 6

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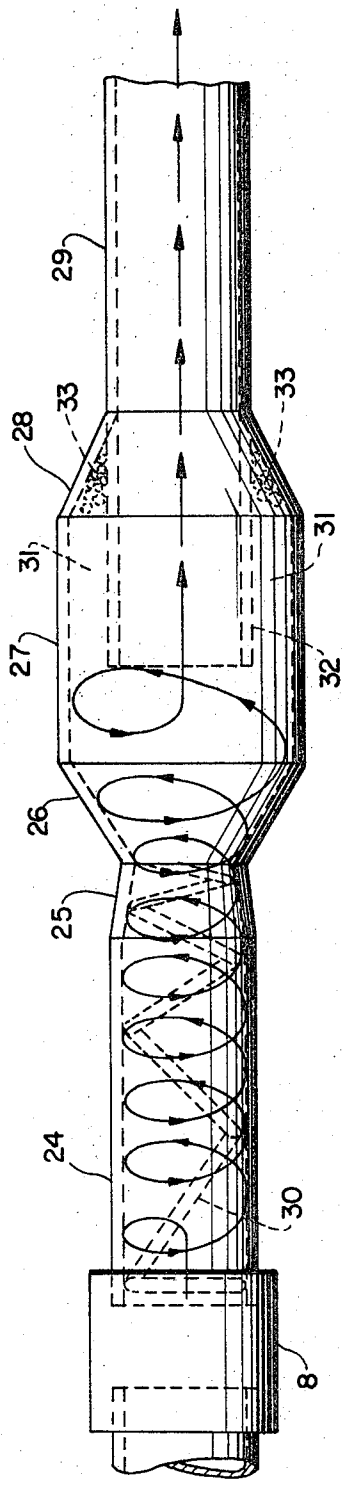


FIG. 8

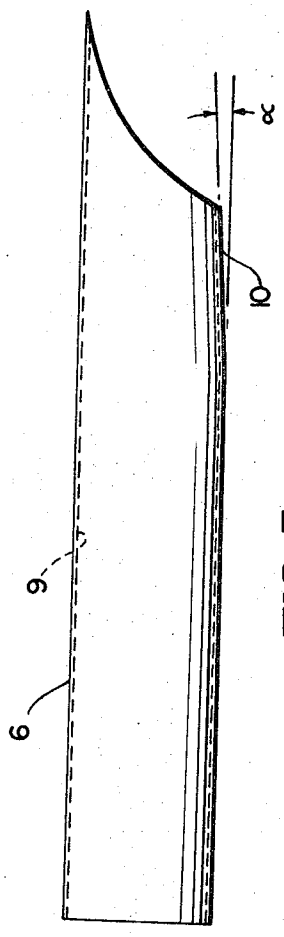


FIG. 5

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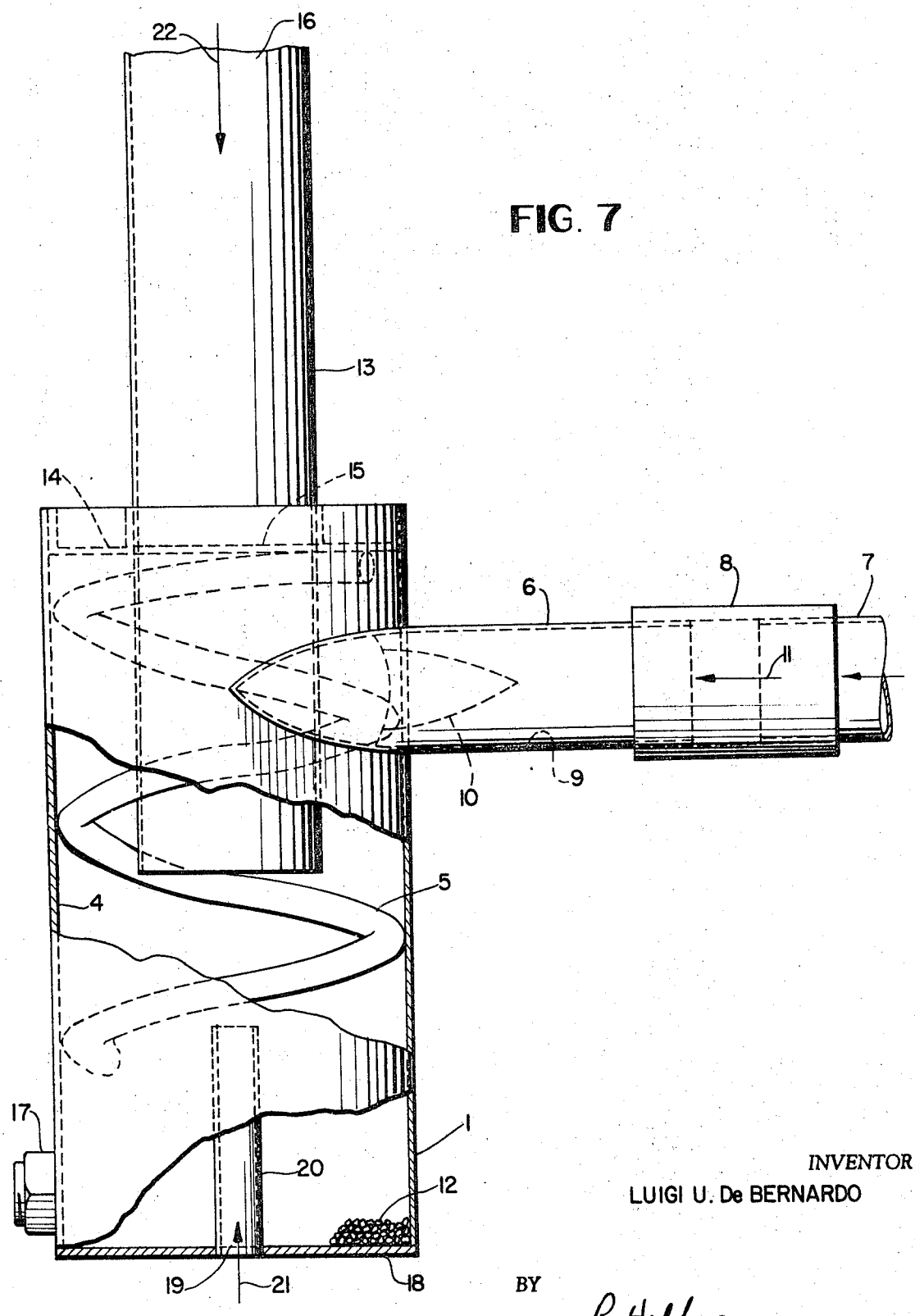


FIG. 7

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APPARATUS FOR REMOVING ENTRAINED PARTICLES FROM GASES

This application is a continuation-in-part of Ser. No. 592,888, filed Nov. 8, 1966, now abandoned.

This invention relates in particular to a novel spark arrester, but which also has the more general utility to remove solid particles entrained in a gas stream. More particularly, it relates to a device for removing entrained incandescent solid particles (sparks) from exhaust gases emitted from internal combustion engines.

All internal combustion engines including those of relatively low horsepower, such as are commonly used on motorcycles, power saws, small pumps, and the like, must frequently be operated in locations, such as forests or fields, where accidental fires could result in extensive property damage and loss of life. It is characteristic of such engines that the exhaust gases contain unburned carbon particles which are emitted with the gases in an incandescent state as sparks. Where these particles are greater than 0.0232 of an inch in diameter, they constitute a serious fire hazard because they fall to the ground still sufficiently hot to ignite any combustible material, such as dry leaves or brush, which may be about. This is particularly true of moderate to large motorcycle engines. For this reason, the engines are provided with devices to remove the sparks from the exhaust gases before they are released into the atmosphere. A similar problem exists with larger engines found on heavy equipment such as tractors, bulldozers, and locomotives.

Prior to this invention, the spark-arresting devices embodied barriers of various designs, such as stationary louvered vanes (or "fans" as they are referred to in the art), perforated or slotted tubes, baffles, or screens. The function of these barriers was to remove sparks from the exhaust gases by (a) causing the sparks in the straight-flowing gases to strike such barriers and fall aside or (b) rotating the flowing gas stream to cause the sparks to be trapped or destroyed by centrifugal action.

Such spark arresters, which operate on an "impact" principle or a "centrifugal force" principle, rely on fixed obstructions of relatively large areas within the arrester housing to remove the sparks. These fixed obstructions increase the back pressure of the exhaust system to an extent dependent on their design and number. Back pressure not only reduces the efficiency of engine performance, but excessive back pressure can cause permanent engine damage. Therefore, low back pressure becomes a major consideration in the design of any spark arrester. However, because a spark arrester must also have sufficient capacity (defined as the flow in cubic feet per minute at a back pressure of 1 pound per square inch) for use with any given engine, such devices are frequently large and bulky. An additional consideration is the fact that small internal combustion engines frequently must be operated in varying positions, as, for example, back-carried engines and those used to operate hand-carried saws. In such cases, the spark arresters must not only be small enough to avoid any undue added weight, but they must also maintain high efficiency regardless of position.

Furthermore, present commercial designs use components that require centers for structural support and to divert exhaust gases through spin-producing devices. These center portions are vulnerable to burnout and vibration failures.

Accordingly, one object of the present invention is to provide a spark arrester which produces a minimum back pressure. Another object is to provide such a device which can be made lighter and smaller than those previously available without reducing its capacity. A further object is to provide a spark arrester which can be operated in any position. Still another object is to provide a small, high capacity spark arrester in which the danger of internal burnout is minimal.

Other objects will become apparent to those skilled in the art from the following description.

The spark arrester provided by this invention operates on the "centrifugal force" principle and utilizes a spiral element within a housing to control the flow pattern of the exhaust

gases. In general, a preferred embodiment comprises an elongated cylindrical housing, closed at one end, provided near the open end with an inlet nozzle for exhaust gases from an internal combustion engine and a spiral guide on the inside wall of the cylinder advancing toward the closed end. The spiral guide takes up but a minor fraction of the cross-sectional area of the cylindrical housing, thereby introducing a minimal impedance to the flow of gases. Thus, by avoiding the use of barriers or baffles of large area, it is now possible to provide a spark arrester of larger capacity relative to its overall size. These results are made possible by the fact that entering exhaust gases are caused to flow as a thin layer along the inner wall of the cylindrical body, as will be described in greater detail below. This is accomplished by mounting the inlet nozzle so that, at one point, its inner diameter is tangent to the inner diameter of the main cylindrical body. The resulting centrifugal force causes the particles, as well as the gases, to remain close to the cylinder wall, where they are directed toward the closed end by the spiral guide. Entrained carbon particles are pulverized at the closed end, or they can be directed into a trap through a narrow slot in the main body of the spark arrester. The gases, however, do not reach the closed end, but reverse their direction and travel in a spiral path along the center of the cylinder as a separate stream inside the advancing spiral stream of gases, and are discharged into the atmosphere through the open end of the cylinder.

One modification falling within the scope of the invention achieves similar results without the necessity of closing one end of the cylinder, thus permitting a straight-through flow of gases. This device further reduces back pressure; but at the cost of slight reduced efficiency.

In order that the invention be more readily understood, reference is made to the following detailed description of the several embodiments and to the accompanying drawings in which:

FIG. **1** is a simplified schematic illustration of the principle upon which the present invention is based;

FIG. **2** is a cross section on line **2–2** of FIG. **1**, showing the relative dispositions of the main cylindrical body, inlet nozzle, and spiral guide, and the relatively unobstructed passageway through the main cylindrical body;

FIG. **3** is a view, similar to that of FIG. **1**, with parts of the main cylinder broken away to the relative disposition of the internal members, of a preferred embodiment of the invention;

FIG. **4** is a view of the same embodiment as shown in FIG. **3**, also with parts broken away, but rotated 90° to look down the longitudinal axis of the gas inlet tube;

FIG. **5** shows a side view of the inlet tube itself, indicating the "ramp," as will be described in detail below;

FIG. **6** is a side view, with parts broken away to show structure, of the means for mounting the gas outlet tube;

FIG. **7** is a modification of the preferred embodiment of FIG. **3** in which a small, axially disposed aspirating tube is, optionally, provided at the closed end of the cylinder; and

FIG. **8** shows another embodiment of the invention in which both ends of the cylinder are open and the gases flow through.

As noted above, FIGS. **1** and **2** represent schematic illustrations of the invention to show the principle upon which it works.

Referring, therefore, to FIGS. **1** and **2**, the invention, in general, comprises a cylinder **1**, having one end closed by any suitable cover means **2**. The other end **3** of cylinder **1** is open to the atmosphere. Secured to the inner wall **4** of cylinder **1**, is a spiral guide member **5** of small diameter and which occupies a relatively small fraction (approximately 1 percent) of the inner cross-sectional area of the cylinder **1**. Spiral guide member **5** is secured in place inside the cylinder by any suitable means, such as by friction fit, welding, soldering, or the like. The spiral may also be formed inside wall by rolling. Spiral guide member **5** begins at a point in from the open end **3** of cylinder **1** and advances toward closed end **2**, ending some distance short of that end. As a point intermediate the ends of guide member **5**, close to the beginning thereof, an

inlet nozzle 6 is secured to cylinder 1. Nozzle 6 serves to introduce exhaust gases from the exhaust pipe 7 (shown in part) which is connected to nozzle 6 by any suitable means, such as sleeve 8. Exhaust pipe 7 is also connected to an internal combustion engine (not shown). In order to achieve a smooth transition of the flow of exhaust gases from the nozzle into the cylinder, nozzle 6 is connected to the cylinder at such an angle that point A of the inner diameter 9 of the nozzle is tangent to the inner circumference of the cylinder. It is also necessary to constrict the nozzle by tapering the side opposite tangent surface 9 to provide a "ramp" 10, as shown in FIG. 2 and also in FIG. 5. Points A and B (FIG. 2) are the plane projections where the inner surface of nozzle 6 intersects the inner surface of cylinder 1. In the manner just described, the linear flow of hot exhaust gases in nozzle 6 is converted to a thin circular flow along the inner wall of cylinder 1 without turbulence. Smooth transition of flow is essential to avoid turbulence so as to maintain the hot gases whirling in a thin layer along the inner wall of the cylinder. This is essential to prevent entrained carbon particles from striking the inner cylindrical surface at an angle that would cause them to bounce off the inner wall into the path of the exiting gases.

Referring again to FIG. 1, it can be seen that entering hot gases, together with entrained hot carbon particles flowing in a path designated by broken arrow 11, are caused by guide member 5 to flow in a smooth spiral stream along the inner wall of cylinder 1 toward the closed end. Because of the constriction in nozzle 6, the exhaust gases and carbon particles enter the cylinder at a relatively high velocity. Centrifugal force causes the carbon particles to stay close to the cylinder wall and follow a spiral path toward closure 2 and impinge on the latter. There the particles are pulverized by their continued spinning motion and finally are reduced to smaller than 0.0232 of an inch, at which size they are no longer considered to be a fire hazard. Because of their greatly reduced mass, they are expelled with exiting exhaust gases.

Referring once more to FIG. 1, it will be observed that, upon entry, the hot particle-containing gases travel toward the closed end of cylinder 1 in a spiral path indicated by arrows 11. After proceeding part way down the cavity, the gases reverse their direction of flow and assume a spiral path 11*a*, of much smaller spinning radius, inside spiral stream 11 in the direction of open end 3 of the cylinder. Since the laws of conservation of momentum must apply, the angular velocity in the exit direction is greatly increased by the decreased spinning radius to provide maximum separating effects capable of producing 100 percent spark arresting efficiencies.

FIGS. 3 and 4 represent a preferred form of the invention.

As seen in FIGS. 3 and 4, the basic device of FIG. 1 is provided with a second smaller cylinder or tube insert 13 coaxial with main cylinder 1. Cylinder 13 is mounted inside a circular, ribbed orifice ring 14 which has a central, circular opening 15 equal to the outside diameter of cylinder 13. Details of the structure of ring 14 are shown in FIG. 6. The outside diameter of ring 14 is the same as the inside diameter 4 of main cylinder 1. Thus, when orifice ring 14 is secured in the open end of cylinder 1 by any suitable means, such as welding, and cylinder 13 is similarly secured in the circular opening 15 of orifice ring 14, the only communication between the atmosphere and the inside of main cylinder 1, is through cylinder 13. The latter extends into cylinder 1 past the point where nozzle 6 is connected to cylinder 1. As the outside diameter of cylinder 13 is also smaller than the inside diameter of spiral guide member 5, the resulting structure comprises the respective coaxial arrangement of main cylinder 1, spiral guide 5, and inner cylinder 13.

In the embodiment under discussion, spiral guide 5 begins at ring 14 and progresses part way toward the closed end of cylinder 1 to a point beyond the end of cylinder 13, as shown in FIG. 3.

Gas stream 11 from exhaust pipe 7 follows a path similar to that indicated in FIG. 1. That is, the gas enters main cylinder 1 tangentially to inner surface 4 and is directed toward the closed end in a thin spiral stream along the inner surface. As in the basic design shown in FIG. 1, the stream reverses itself and follows a coaxially spiral path 11*a*, of smaller spinning radius, back toward the exit end through tube 13, from which it exhausts to the atmosphere through the open end 16 of cylinder 13, leaving behind a pulverized deposit of carbon particles 12. These particles when their mass has been sufficiently reduced will be expelled with exiting exhaust gases. A removable cleanout plug 17 is provided for inspection of cylinder 1 and removing, if required, accumulated carbon particles 12. The diameter of tube 13 is, essentially, dependent on the diameter of opening 15 in ring 14 which is selected to improve spark arresting efficiency. Ring 14 further serves to restrict the diameter of main cylinder 1 to provide optimum flow rate and back pressure characteristics. Although the tube 13 is optional, its use provides the added advantage of better noise supression. Noise may be further reduced by adding baffles (not shown) inside tube 13.

The device just described can optionally be modified to provide for sucking in a stream of cool air during operation.

Referring to FIG. 7, it is seen that the device is the same as that of FIG. 3 except that the closure plate 2 is replaced by a plate 18 having a small opening 19 in its center in which there is secured a short aspirating tube 20. This tube, having a diameter about one-twelfth of the inside diameter of cylinder 1, is of sufficient length to extend inward to a point at least inside the last turn of spiral guide 5 nearest the closed end of main cylinder body 1. During operation, when the whirling stream of gases 11 reverse direction and proceed toward the open end as the more rapidly whirling spiral 11*a*, the zone of low pressure in the center of the resulting vortex causes a stream of cool air 21 to be drawn axially into the cavity of main cylinder 1, thus assisting to cool the hot exhaust gases and the entrained hot carbon particles. This aspirated air is picked up by the rapidly swirling stream 11*a* and is exhausted together with the latter through tube 13. Furthermore, stream 11*a* swirls so rapidly that the pressure in the vortex at exit end 16 is low enough also to suck cool air 22 into the vortex at end 16. This air is also picked up by spiral stream 11*a* and exhausted. In test runs with this embodiment, the pressure in the center of the vortex was so low that even solid particles were sucked in, giving the illusion that these particles were travelling upstream into the exit end of the apparatus.

In FIG. 8 there is shown still another modification which, although also operating on the centrifugal force principle, differs in many important structural features from the apparatus of FIGS. 1, 3, and 7. In this modification the side entrance nozzle is omitted. Carbon-containing gases enter at one end and leave at the other end of a generally cylindrical member.

Referring specifically to FIG. 8, exhaust pipe 7 from an internal combustion engine (not shown) is connected by means of any suitable sleeve member 8 to the inlet end 23 of a first elongated cylindrical member 24. The other end 25 of cylinder 24, slightly constricted in cross section, is joined to the narrower end of a first conical section 26. The latter is connected at its wider end to one end of a second, short cylindrical section 27 which is of greater diameter than cylinder 24 and which is, in turn, joined at its other end to the wider end of a second conical section 28, equal in size to conical section 26. A third cylindrical member 29, of the same diameter as cylinder 24, is joined to the smaller end of the second conical section 28 and is of such length that it extends into the second cylindrical member 27. As shown in FIG. 8, cylinder 24, cone 26, cylinder 27, cone 28, and cylinder 29 are, successively, joined on a common longitudinal axis.

As in the previously described embodiments, the spark arrester of FIG. 8 is provided with a spiral guide member 30 of such diameter that it occupies no more than about 1 percent of the cross-sectional area of elongated cylinder 24. As in the previously described embodiments, its purpose is to impart a whirling motion to the exhaust gases entering the input end 23 of cylinder 24. However, whereas the spirals of FIGS. 1—4 and 7 can be of uniform pitch, if desired, because the gases

enter the main body of the arrester in a tangential direction, the gases in this modification are introduced axially and a spiral motion must be imparted gradually to avoid turbulence at the inlet. For this reason, the initial convolution of spiral **30** is of a relatively large pitch which decreases progressively in the direction of conical section **26**. Exhaust gases entering at **23** are given a gentle rotating motion which increases in velocity as the pitch decreases. At constriction **25** the gases are given an additional axial velocity as they pass through the constricted area and enter section **26**. Centrifugal force and momentum of the entrained carbon particles cause the latter to continue in a spiral path of increasing diameter along the inside walls of cone **26**, into cylinder **27** and cone **28**, into the pocket **31** formed by cone **28** and the inward extension **32** of cylinder **29** where they form a partially pulverized deposit **33**. The gases, however, still in a spiral path, pass through cylinder **29** from which they are exhausted to the atmosphere.

In one specific device constructed according to FIG. **8**, the spark arrester had an overall length of about 20 inches, while cylinder **24** had an inside diameter of about 1⅜ inches and was about 10 inches long. Cylindrical portion **27** was 2½ inches in diameter, was 6 inches long, and was joined at each end to 23° conical sections **26** and **28**. The inwardly extending portion of cylinder **29** was 4 inches in length, and the pitch of the initial convolution of spiral **30** was 6 inches. It will be obvious, however, that these dimensions can be varied proportionately according to the desired capacity of the spark arrester and its intended use, without departing from the spirit of the invention.

In the foregoing description of the preferred embodiment of the apparatus of this invention, the several components were referred to generally in terms of their function and structural relationships.

Referring once more to FIGS. **3** and **4**, the preferred embodiment of the invention comprises a main cylinder body, which is closed at one end and has a reduced opening at the opposite (outlet) end. For greatest efficiency, it has been found that the inlet nozzle **6** should have a diameter of approximately one-third the diameter of the main cylinder body **1** and ramp **10** should have a slope of about 4° (the angle α in FIG. **5**). This results in a smooth transition from linear exhaust flow in the nozzle to a circular flow in the main cylinder body and eliminates carbon "bounce" (i.e., rebound of carbon particles from the cylinder walls into the outlet stream). The nozzle tube itself may have any convenient length in excess of the ramp length.

For the most efficient operation, the circular opening **15** of orifice ring **14** and, therefore, the outside diameter of the tube insert **13** should have a diameter of about half that of the main cylindrical body **1**. Tube **13** should extend inward toward the closed end of cylindrical body **1** for about half the length of the latter. The length of the external portion of tube **13** is not critical and may be cut to suit.

As mentioned previously, the spiral guide member **5** occupies a relatively small portion of the cross-sectional area of the main cylindrical body. It has been found that, in embodiments having a closed end, a single spiral of constant pitch and a cross-sectional area of about 1 percent of the main body cross section results in the highest separation efficiency. Optimum efficiency can be obtained with a spiral guide whose cross-sectional area may be as small as 0.5 percent of the cross-sectional of cylinder **1**. The spiral guide originates at the point where it contacts orifice ring **14** and extends toward the closed end of cylinder **1** for not more than 75 percent of the main body axial length. Although a single turn has been found to be quite effective, it is preferred that the spiral guide have about 2 to 2½ turns for best results. Also, starting from the open (exit) end of the main cylinder body, the coil origin must precede the nozzle entrance. Although, for best results, it is preferred to locate the nozzle entrance with the first turn of the spiral, the distance of the nozzle from the exit end may be greater.

As already mentioned in the description of the embodiment of FIG. **8**, the diameter of the spiral rod or wire **30** should be such as to occupy no more than about 1 percent of the cross-sectional area of cylinder **24**.

The above-described spark arrester has the advantage that no center portions are present which can lead to burnout and vibration failures and which would tend to increase operating back pressures to undesirable levels.

In comparative tests with commercially available devices of varying design, the present apparatus exhibited efficiencies of 100 percent at engine speeds above idle and at extremely high rates of exhaust flow, permitting its use on weapons loaders.

A nonexclusive, irrevocable, royalty-free license in the invention herein described, throughout the world for all purposes of the U.S. Government, with the power to grant sublicenses for such purposes, is hereby granted to the Government of the United States of America.

I claim:

1. Apparatus for removing entrained hot particles from internal combustion engine exhaust gases comprising:

a. an elongated cylinder having an inlet port in the cylinder wall near one end;

b. an inlet nozzle secured to the cylinder at said inlet port at such angle that an inner wall of said nozzle is tangent to the inner wall of the cylinder at their point of contact, said nozzle having a decreasing taper in the direction of the cylinder, said decreasing taper being obtained by providing a flat, ramplike portion on the side of the nozzle opposite to the tangent wall;

c. means for connecting the nozzle to the exhaust pipe of an internal combustion engine; and

d. a spiral guide member secured to the inner wall of the elongated cylinder, said spiral advancing from a point between the inlet port and the proximal open end of the cylinder for a distance not more than 75 percent of the length of the cylinder, said spiral guide member comprising approximately 1 percent of the cross-sectional area of the cylinder.

2. Apparatus for removing entrained hot particles from internal combustion engine exhaust gases comprising:

a. a first elongated cylinder having a closure plate at one end, an open end, and an inlet port in the cylinder wall near the open end;

b. an inlet nozzle connected to said first cylinder at said inlet port at such an angle that an inner wall of the nozzle is tangent to the inner wall of said first cylinder at their point of contact; said nozzle having a decreasing taper in the direction of said first cylinder, said taper being obtained by providing a flat, ramplike portion on the side of the nozzle opposite the tangent wall;

c. means for connecting the nozzle to the exhaust pipe of an internal combustion engine;

d. a spiral guide member secured to the inner wall of said first elongated cylinder, said spiral commencing at a point between the open end of the cylinder and the inlet port and advancing toward the closed end of the cylinder for a distance not more than 75 percent of the length thereof, said spiral guide member comprising approximately 1 percent of the cross-sectional area of said first cylinder;

e. a second elongated cylinder, having a smaller diameter than the first cylinder, disposed coaxially in said first cylinder and extending outward through the open end thereof; and

f. ring means inside the open end of the first cylinder for securing the second cylinder and for closing the annular space between said first and second cylinders.

3. The apparatus of claim **2** wherein the diameter of the second cylinder is about one-half that of the first cylinder and extends inward for about half the length of said first cylinder.

4. The apparatus of claim **2** wherein the spiral guide member is of uniform pitch and advances toward the closed end of the first cylinder for from 2 to 2½ turns, commencing at the ring means.

5. The apparatus of claim **4** wherein the entry port is located within the first turn of the spiral guide member.

6. The apparatus of claim **2** wherein the closure plate is replaced by a plate having a central opening therein and an aspirating tube extending coaxially inward from said central opening.

7. The apparatus of claim 6 wherein the central opening in the closure plate and the aspirating tube are about one-twelfth the diameter of the first cylinder and said aspirating tube extends inwardly to a point within the last turn of the spiral guide member.

8. Apparatus for removing entrained hot particles from internal combustion engine exhaust gases comprising:

a. a first elongated cylinder having an inlet end for receiving hot exhaust gases, and an outlet end;

b. a second elongated cylinder having a diameter equal to that of the first cylinder for ejecting gases to the atmosphere;

c. a third cylinder intermediate the first and second cylinders having a diameter greater than that of said first and second cylinders, said three cylinders being all disposed on a common axis;

d. a first connecting piece joining the outlet end of the first cylinder with the proximal end of the third cylinder, said first connecting piece having a first conical portion tapering inward from the outlet end of the first cylinder to a diameter smaller than that of the first cylinder, followed by a second conical portion tapering outward to a diameter equal to that of the third cylinder to join the outlet end of the first cylinder to the proximal end of the third cylinder;

e. a second connecting piece comprising a conical member extending from the distal end of the third cylinder to a point intermediate the ends of the second cylinder, whereby the second cylinder extends through said second connecting piece into the third cylinder, the outer surface of the second cylinder and the inner surface of the second connecting piece together defining an entrapment zone for solid particles entrained in the incoming exhaust gases; and

f. spiral guide means of decreasing pitch on the inside wall of the first cylinder for imparting a spiral motion to incoming exhaust gases, said spiral guide means comprising approximately 1 percent of the cross-sectional area of the first cylinder.