

PULSED CORONA DISCHARGE APPARATUS WITH RADIAL DESIGN

This invention relates to a pulsed corona discharge apparatus to remediate a contaminated fluent material. More particularly, the fluent material is passed through a reactor vessel having a plurality of electrically interconnected wire electrodes each circumscribed by a second electrode. A high voltage pulse to the wire electrodes generates a streamer corona discharge that breaks down the contaminants in the fluent material to more innocuous constituents. A radial design of the present invention increases the exposed electrode surface area by nesting an inner electrode in an outer electrode.

Fluent materials, typically gases, but also including liquids, are frequently contaminated with hazardous or odiferous materials, such as volatile organic compounds. Before discharging the fluent material to the environment, it is desirable, and may be legally mandated, that the hazardous compounds be remediated by removal or destruction. Methods to remediate hazardous compounds suspended within a fluent material include high temperature thermal incineration, catalytic incineration and absorption utilizing materials such as activated carbon. These methods tend to be expensive and have a low through-put.

Another approach is to break down the hazardous compounds into innocuous materials, such as water and carbon dioxide, by reacting the hazardous compounds with a stream of high energy electrons generated by a partial electrical breakdown of the fluent material. This method is disclosed in United States Patent No. 5,236,672 to Nunez et al. and in United States Patent No. 5,490,973 to Grothaus et al.

The Grothaus et al. patent discloses a reactor having a wire electrode that extends along a longitudinal axis of a tubular electrode circumscribing the wire electrode. Insulators at the entrance and exit of the tubular electrodes center the wire electrode along the axis the tubular electrode, provide tension to the wire electrode to prevent sagging, electrically isolate the wire electrode from the tubular electrode, and provide a gas seal to prevent the flow of gas to parts of the reactor other than the tubular electrode. The insulators are baffled to allow for the ingress and egress of the fluent material and gases are introduced into each reactor tube separately. As a result, complicated gas seals are required, the through-put is low and the number of machine parts required is high.

In addition, the Grothaus et al. patent discloses a method of control of the high voltage power supply that does not detect and so may lead to a failure to remediate the hazardous gas and to possible destruction of the reactor itself.

Operation of spark gap switches results in erosion of the switch electrodes, thereby
5 increasing the gap length. Electrode erosion is a function of current that has been passed through the electrodes and the length of time the current flows through the electrode. A particular switch configuration typically has an erosion rate measured in micrograms per coulomb of total charge transferred through the switch electrodes. (Total charge transfer is the cumulative time integral of the absolute value of the current passing through the switch.)
10 A typical value for switch erosion is 100 to 200 micrograms per coulomb. In a particular circuit, the breakdown voltage of the switch is usually set by adjusting the pressure (density) of the switch gas dielectric, e.g. air or sulfur hexafluoride (SF₆).

Once the electrodes erode and the gap expands to a certain point, the breakdown voltage can no longer be adjusted to the desired value by changing the density of the switch
15 gas. At that point, the switch is no longer operational.

In the design of a conventional axial-spark switch, insulating material is exposed to debris from sparking, which tends to contaminate the insulating material thereby reducing the operational life of the switch.

U.S. Patent Number 5,502,346 (Hsieh) discloses an electro-chemical generator to
20 produce, for example, ozone. This apparatus uses an insulating tube inserted into a ground electrode tube.

U.S. Patent Number 4,126,808 (Rich) discloses a high voltage two stage triggered vacuum gap with high voltage terminals at opposite ends of an envelope. Vacuum switches use plasma generators to inject plasma into the switch gap.

25 U.S. Patent Number 3,996,438 (Kurtz) discloses a vacuum-type circuit interrupter with two pluralities of rod electrodes in which the first plurality of electrodes interleave with the second plurality of electrodes.

U.S. Patent Number 3,854,068 (Rich) discloses a shield structure for vacuum arc discharge devices.

30 As can be seen from the present state of the art, there exists a need for a switch that can operate at voltages in excess of 1 kV where the switch operational lifetime exceeds a total charge transfer of one million Coulombs, particularly for continuous repetitive operation.

There also remains a need for a pulsed corona discharge apparatus suitable to remediate a contaminated fluent material that does not have the disadvantages of the prior art discussed hereinabove.

Accordingly, it is an object of the invention to provide a reactor for remediating a
5 contaminated fluent material with a pulsed corona discharge. Among the features of the invention are that there is a single common header plate electrically interconnected to a plurality of first electrodes and a common reactor plate electrically interconnected to a plurality of second electrodes with a second electrode concentrically disposed about each first electrode. Another feature of the invention is that the second electrodes are tubular and
10 provide a plurality of channels to receive the contaminated fluent. A single inlet effectively communicates the contaminated fluent to all tubular electrodes and a single outlet effectively removes the remediated fluent. Still another feature of the invention is that intermittent high voltage pulses are applied to the header plate by a power supply and distributed to the plurality of first electrodes.

15 Among the advantages of the invention are that the reactor has a simplified design requiring a limited number of machine parts. A further advantage is that the power supply is readily separated from the reactor to facilitate part replacement and cleaning of the reactor. Another advantage of the invention is that electrical power is controlled in such a way that improper high voltage discharges will be detected and corrected. Yet another advantage of
20 the invention is that the pulsed corona discharge effectively remediates contaminated fluent material.

In accordance with the invention, there is provided a system for treating a contaminated fluent. The system includes a power supply capable of providing intermittent pulses of high voltage to an electrically conductive header plate. A plurality of first
25 electrodes are electrically interconnected to that header plate. A plurality of second electrodes, each of which is concentrically disposed about one of the first electrodes defines a plurality of channels to contain the contaminated fluent. An electrically grounded reactor plate is electrically interconnected to each of the plurality of second electrodes and electrically isolated from both the header plate and the plurality of first electrodes. An inlet
30 introduces the contaminated fluent to each of the channels and an outlet recovers a remediated fluent.

The present invention increases the operational life of a spark switch by increasing the amount of exposed electrode surface area.

5 A second embodiment of the present invention is directed to a spark switch having a first end plate and a second end plate. An inner electrode having an outer wall; and an outer electrode. Both the inner electrode and outer electrode are disposed between the first and second end plates and bonded thereto. The outer electrode defines a cavity for receiving a portion of the inner electrode, and the outer wall of the inner electrode and the cavity of the outer electrode form a radial gap.

10 An insulating material is disposed in a sleeve-like configuration around the outer electrode. The insulating material is protected against exposure to contaminants during switching because the outer electrode acts as a barrier to switching by-products.

A third embodiment is directed to a coaxial switch that has electrodes connected to electrical connectors. An insulating material is at either end of the coaxial switch and there are means to maintain the position of the insulating material. This embodiment has a
15 conducting tube connected to an electrical source and an electrical load to provide a path for return current from the load to the source.

A fourth embodiment is directed to a third electrode nested within the inner electrode and thereby forming an additional radial gap.

20 A fifth embodiment is directed to a switch having inlet and outlet ports so that accumulated debris may be removed.

The above stated objects, features and advantages will become more apparent from the specification and drawings that follow:

Figure 1 illustrates in longitudinal cross-sectional representation the reactor portion of the system of the invention.

25 Figure 2 illustrates in transverse cross-sectional representation the header plat of the invention.

Figure 3 illustrates in transverse cross-sectional representation a plurality of second electrodes circumscribing the first electrodes in accordance with the invention.

30 Figure 4 illustrates in longitudinal cross-sectional representation the power supply portion of the system of the invention.

Figure 5 is a side elevation cross-section of a conventional type axial-spark gap switch as known from the prior art.

Figure 6 is a side elevation cross-section of a spark switch constructed in accordance with this invention.

Figure 7 illustrates an embodiment of the switch in which the electrodes are elongated.

5 Figure 8 shows a cross sectional top view of the spark switch.

Figure 9 shows an embodiment having multiple nested electrodes.

Figure 10 shows a coaxial spark switch.

Figure 11 shows the coaxial spark switch connected to an electrical source and to an electrical load

10 A system for treating a contaminated fluent in accordance with the invention has two sections, a reactor section 10 that treats a contaminated fluent and a power supply section 12 that provides intermittent pulses of high voltage electric power to the reactor section. The reactor section 10 is illustrated in Figure 1. A portion of the power supply section 12 is illustrated in Figure 1. The entire power supply section 12 is illustrated in Figure 4.

15 Figure 1 illustrates the reactor section 10 in cross-sectional representation. The reactor section 10 includes an electrically conductive header plate 14 that is preferably formed from an electrically conductive metal such as stainless steel.

 A plurality of first electrodes 16 are electrically interconnected to the header plate 14. Electrical interconnection is by any means effective to support the first electrode 16 under
20 tension and includes bolting, welding, soldering and brazing. High voltages will be transferred from the header plate 14 to the first electrodes 16 through the electrical interconnection, so low electrical resistance attachment means are preferred. A most preferred attachment means is bolting, that has the additional advantage that the first electrodes 16 may be readily replaced.

25 The first electrodes 16 are of any desired shape and formed from any suitable electrically conductive material. Preferred materials for the first electrodes include stainless steel. A preferred shape for the first electrode is a wire having a generally circular cross-section with a diameter of from about 0.001 inch to about 0.1 inch. More preferably, the diameter of the first electrodes is from about 0.01 inch to about 0.05 inch.

30 Figure 2 is a cross-sectional view of the reactor system illustrated in Figure 1 viewed along section line 2-2. Figure 2 shows that the first electrodes 16 are disposed about the header plate 14. Preferably, a plurality of first electrodes 16 are symmetrically oriented about

a longitudinal axis 18 of the reactor section. While Figure 2 illustrates eight first electrodes, any number amenable with a respective reactor design may be utilized. Preferred systems are believed to include from one to twenty first electrodes.

Referring back to Figure 1, an electrically conductive reactor plate 20 is spaced from
5 and electrically isolated from the header plate 14. The reactor plate 20 is formed from an electrically conductive metal, preferably stainless steel. The reactor plate is sufficiently strong to support a plurality of second electrodes 22. Typically, the reactor plate has the thickness of from about 0.125 inch to about 1.5 inches and more preferably, the thickness from about 0.5 inch to about one inch.

10 Electrical isolation between the header plate 14 and the reactor plate 20 is provided by the fluent material around the periphery of the header plate 14 and at first apertures 24 that extend through the reactor plate 20. The first apertures 24 facilitate entrance of the first electrodes 16 into the bore of tubular second electrodes 22. Preferably, the second electrodes 22 are concentrically disposed around the first electrodes 16.

15 High voltage pulses applied to the header plate 14 drive electric discharges between the first electrodes 16 and the second electrodes 22, with the discharge completely contained within the volume of the tubular electrode 22. To ensure the discharge is created only within the volume enclosed by the second electrodes 22, the minimum distance 26 between the first electrode 16 and the reactor plate 20 should be at least equal to the distance between the first
20 electrode 16 and the second electrode 22. Additionally, the first apertures 24 should be shaped such that the electric field in the region of the first apertures 24 does not exceed the electric field found between the first electrode 16 and the second electrodes 22.

Further electrical isolation between the header plate 14 and the reactor plate 20 is provided by a centrally disposed dielectric material 28. The dielectric material 28 is bonded
25 to both the reactor plate 20 and to the header plate 14 and maintains the two components a fixed distance apart. The dielectric 28 is any suitable electrically non-conductive material having a breakdown voltage greater than the voltage applied by the power supply section 12. Suitable materials for the dielectric 28 include ceramics and polymers. Polymers are preferred since attachment of the dielectric 28 to both the reactor plate 20 and the header
30 plate 14 is preferably by a mechanical means such as through the use of screws and the machinability of a polymer is an advantage. A preferred polymer is polytetrafluoroethylene (TEFLON, a trademark of DuPont, Wilmington, DE).

As illustrated in Figure 2, the dielectric 28 is centrally disposed relative to the first electrodes 16 whereby the first electrodes 16 are unimpeded by the dielectric 28. The diameter of the dielectric 28 should be sufficiently large to prevent tension variation between respective first electrodes 16 from shifting the header plate 14 to a non-parallel orientation relative to the reactor plate 20. Preferably, the diameter of the dielectric 28 is at least 40 % of the diameter of the header plate 14. For example, if the header plate 14 is a circle with a diameter of 6.25 inches, then the dielectric has a diameter of about 2.50 inches.

The thickness of the dielectric 28 is that effective to prevent electric arcing between the header plate 14 and the reactor plate 20 and, with reference back to Figure 1, the distance 30 is from about 0.25 inch to about 2 inches and more preferably from about one inch to about two inches.

The dielectric 28 also serves to locate the header plate 14 at a fixed distance from the reactor plate 20 such that each first electrode is located concentrically relative to the second electrode through which that second electrode passes.

A pulsed corona discharge is formed extending between the first electrodes 16 and the second electrodes 22. The voltage potential electrically required to establish the discharge between the first electrode 16 and second electrode 22 is formed by raising the first electrodes 16 to sufficiently high voltage to form the discharge and by having the reactor plate 20, and electrically interconnected second electrodes 22, at ground potential 32. The high voltage may be either positive or negative relative to the grounded component.

Connected to the reactor plate 20, and circumscribing the reactor plate 20 and header plate 14 to form a gas receiving cavity 34, is gas manifold 36. The gas manifold 36 is hermetically sealed to the reactor plate 20, such as by flange 38 that is bolted, welded, brazed or otherwise joined to the reactor plate 20. Preferably, a compliant O-ring (not shown) may be disposed between the flange 38 and the reactor plate 20. When a contaminated fluent 40 is delivered to the gas receiving cavity 34 through inlet 42, the contaminated fluent 40 fills the gas receiving chamber 34 and flows down a plurality of channels 44 formed by second electrodes 20. The combination of the gas manifold 36 and reactor plate 20 containing first apertures 24 results in the inlet 42 effectively providing contaminated fluent 40 to each reaction chamber defined by the combination of a second electrode 22 and first electrode 16. It is not necessary to provide a separate gas inlet to each reaction chamber and separate baffling to each channel 44 is not required.

The gas manifold 36 is formed from any suitable material. To minimize electric shock hazard, the gas manifold 36 is preferably formed from an electrically conductive material such as stainless steel.

5 The second electrodes 22 are electrically interconnected to the reactor plate 20 and extend in a direction away from the header plate 14 for an extended distance. The length of the second electrodes 22 define the reaction chamber length and the time during which contaminated fluent is in contact with the corona discharge and subject to remediation. Typically, the length 44 of the second electrodes 22 is from about six inches to about 60 inches.

10 The second electrodes are typically tubular with an inside diameter 46 of from about 0.5 inch to about 3 inches.

Figure 3 is a cross-sectional representation of the reactor section 10 viewed along section line 3-3 and illustrates a plurality of reaction chambers comprising the combination of a second electrode 22 and first electrode 16 extend within the reactor housing 48. The volume of reaction chamber effective to remediate contaminated fluent is the product of the number of reaction chambers multiplied by the length of each chamber times the cross-sectional area of each chamber. For a reactor having eight reaction chambers, each with a length of 36 inches and an inner diameter of one inch, the total effective volume is 226 inches.

20 The second electrodes 22 are formed from a suitable electrically conductive material that resists deformation and erosion from contact with an electric arc and heating due to a pulsed corona discharge. One suitable material for the second electrode 22 is stainless steel. A suitable wall thickness for the second electrode is from about 0.05 inch to about 0.2 inch.

Referring back to Figure 1, the second electrodes 22 terminate at a down stream reactor plate 50 that is preferably formed from an electrically conductive material and more preferably from the same material as the reactor plate 20. Second apertures 52 extend through downstream reactor plate 50 and discharge remediated fluent 54 from the reaction chambers. The second apertures 50 preferably have a size and shape that is similar to the first apertures.

30 The remediated fluent 54 may be discharged directly to the atmosphere, or preferably, is contained within a gas discharge cavity 56 where a sensor 58 determines the level of volatile organic compounds or other hazardous materials. If the hazardous material content is

sufficiently low, the remediated fluent 54 is discharged through outlet 60. If the hazardous material content is too high, a restrictor 160 is partially closed so that the flow rate of the fluent material through the reactor is slowed and the remediation level is thereby increased.

Alternatively, and preferably, the sensor 58 is in a feedback loop with the power supply control unit (79 in Figure 4) so that the electrical power delivered to the reactor is adjusted automatically to respond to variations in the exhaust fluent pollutant concentration. If the concentration increases, the sensor 58 causes the power supply control unit to increase the electrical power to the reactor. As the exhaust concentration then stabilizes at a value predetermined and programmed into the power supply control unit by an operator, the sensor 58 causes the control unit to reduce the electrical power to the reactor. The electrical power delivered to the reactor may be controlled by adjusting the voltage delivered to the header plate or, preferably, by adjusting the pulse repetition rate. The power delivered to the reactor is roughly proportional to the voltage squared times the repetition rate. This automatic feedback and control of the exhaust concentration is advantageous in ensuring efficient operation of the system during periods of fluctuating inlet pollutant concentration.

The gas discharge cavity 56 is bordered by the downstream reactor plate 50 and an end cap 62 that is hermetically sealed to the downstream reactor plate 50 and provides sufficient room for the gas discharge cavity 56 as well as a tension plate 64. Preferably, the end cap 62 is formed from an electrically non-conductive material to prevent unintentional contact with the electrodes that may be at a high voltage potential. The end cap 62 may also be formed from an electrically conductive material to provide shielding of the high voltage components.

The tension plate 64 supports the first electrode 16 and in cooperation with header plate 14 maintains the first electrodes under tension and substantially parallel to the longitudinal axis 18 and centered within each of the second electrodes 22. Preferably, the tension plate 64 is formed from an electrically conductive material such as stainless steel.

The tension plate 64 may be supported by the downstream reactor plate 50 utilizing a dielectric substantially similar to the dielectric 28 or, alternatively, as illustrated in Figure 1, bonded to the end cap 62 by a polymer adhesive 66, or mechanical means such as bolts or screws.

An opening in the gas manifold 36 receives an interconnect portion 68 of the power supply portion 12. An interface 70 between the power supply section 12 and the reactor

section 10 is hermetic, such as by insertion of an o-ring, gasket or other suitable means.

Preferably, the power supply section 12 is permanently attached to the manifold 36 so that the power supply section may be disconnected from the reactor section 10 at the flange 38 and reactor plate 20 interfaces facilitating replacement of parts and interchangeability of

5 components.

Alternatively, the interface 70 is such that the interconnect portion 68 is readily removed to separate the power supply section 12 from the reactor section 10. Centrally disposed within the interconnect portion 68 is a power supply electrode 72. The power supply electrode is any electrically conductive material, such as a copper alloy or stainless

10 steel. The interconnect portion 68 is electrically insulating.

A front portion 74 of the power supply electrode 72 applies a compressive force on a detachable contact, such as leaf spring or compression spring 76. The compression spring 76 is formed from an electrically conductive material such as stainless steel and also contacts the header plate 14 to form a low resistance electrical contact between the power supply

15 electrode 72 of the power supply section 12 and the header plate 14. Since the compression spring 76 is not mechanically or chemically bonded to the header plate 14, separation of the power supply section from the reactor section is facilitated and alignment of the two is not critical. As best illustrated in Figure 2, the compression spring 76 typically contacts a centrally disposed portion of the header plate 14 to provide electrical energy to each of the

20 first electrodes 16.

The power supply portion 12 is illustrated in cross sectional representation in Figure 4. An alternating current (AC) power source 78, such as a 120 volt, 60 cycles per second intermittently delivers an alternating current to a power supply 80 that converts the low voltage AC to high voltage direct current (DC).

25 The DC power supply 80, converts the alternating current from the AC power supply 78 to a direct current output voltage 84 that is in excess of 20 kilovolts, and preferably is between about 30 kilovolts and about 40 kilovolts. The output voltage 84 is conducted to isolation resistor 86 that is in series with the DC power supply 80. The isolation resistor has a resistivity of at least 20 ohms and the resistivity is preferably about 100 ohms. The

30 isolation resistor electrically isolates the power supply 78 from a high speed switch 88.

The output current 89 is conducted from the isolation resistor 86 to a capacitor 90 then to ground. The capacitor 90 stores electrical energy of at least 0.05 joule, and preferably

approximately 1 joule is contained. The high speed switch 88 then closes connecting the capacitor 90 to the header plate (20 in Figure 1) via the power supply electrode 72 conducting a voltage pulse of between about 10 kilovolts and 200 kilovolts.

The voltage on the capacitor 90 energizes a first electrode 92 of the spark gap switch 88. When the voltage charge applied to the first electrode 92 exceeds the breakdown voltage of a gap 94 contained within spark gap switch 88, an arc connects the first electrode 92 to the spark gap second electrode 96 energizing the power supply electrode 72.

The spark gap 94 is filled with any suitable gas, including air. Hydrogen is preferred since the voltage recovery characteristics of hydrogen allows high pulse repetition rates.

The high speed switch delivers voltage pulses on the order of from about 5 nanoseconds to about 1 microsecond with the interval between pulses being in the range of from about 100 microseconds to about one second.

A feedback loop 99 between the DC power supply 80 and the control unit 79 indicates when a discharge has occurred in the output circuit of the DC power supply. This discharge may be the desired discharge in the reactor section 10 or it may be an undesired discharge anywhere else in the high voltage circuit. On receipt of a signal from the feedback loop 99, the control unit 79 prevents further charging of capacitor 90 by DC power supply 80. When the desired inter-pulse interval has elapsed, the control unit 79 allows the DC power supply to begin charging the capacitor 90 for another cycle.

Synchronization provided by feedback loop 99 is desired so the DC power supply 80 is completely isolated from the capacitor 90 immediately following closure of the high speed switch 88. Otherwise, the DC power supply would deliver energy directly to the reactor section 10 in an inefficient manner.

Referring back to Figure 1, when the power supply electrode 72 applies a voltage pulse to the header plate 14, each of the first electrodes 16 are brought to that same voltage potential. When the voltage potential exceeds the breakdown voltage of the fluent material, a stream of electrons 100 flows between the first electrode 16 and the second electrode 22 in the form of a high energy corona. As the contaminated fluent 44 passes through the energized electrons 100, collisions between the fluent material and the electrons create highly reactive species called radicals. The radicals, in turn, react with and destroy the pollutant species breaking them down into more innocuous materials such as O_2 , N_2 , CO_2 and H_2O .

Referring back to Figure 4, if the voltage is applied to the first electrodes for an excessively long period of time, the process efficiency is reduced due to acceleration of ionic species in the fluent gas. This will ultimately result in a thermal arc with attendant energy inefficiency, reduced treatment volume and electrode damage. Therefore, the high voltage pulse is kept short by the particular design of the power supply section 12.

While the power supply section 12 has been described in combination with the reaction section 10 of the pulsed corona discharge apparatus of the invention, the power supply section has utility for any application that requires short duration pulses of high voltage electricity.

Spark gap switches are often the most rugged switches available for high-peak-power systems. However, they are generally limited to less than 500,000 Coulombs of operational life, where 1 coulomb is the charge transferred by the flow of a current of 1 Ampere for one (1) second.

The operation of a spark gap switch produces spark breakdown current between the electrodes. Spark breakdown current is current flow between electrodes, which produces a hot plasma having gaseous, molten and solid debris as a by product. Spark breakdown current is detrimental to the surface of the electrodes and causes them to become pitted and eroded. Debris from the spark breakdown current also degrades any surrounding materials such as insulating materials used to hold the electrodes in place.

The present invention also discloses a new and improved spark switch design that inserts an inner electrode into an outer electrode, thereby increasing the amount of material that can be eroded before changing the gap length, and thereby increasing the operational life of a switch. The design also enables the outer electrode to serve as a containment vessel thereby restricting the trajectory of debris caused by the breakdown current.

Figure 5 shows a conventional axial-spark switch 201. The exposed electrode surface area is limited to the exposure of an upper electrode plate 180 to a lower electrode plate 190.

The design of the two electrode plates 180, 190 exposes insulating material 130 that is typically acrylic, ceramic, or other insulating material surrounding the electrode plates 180, 190 to spark debris caused by spark breakdown. The gap 210 between electrode plates 180, 190 is typically air or other suitable gas such as, sulfur hexafluoride (SF₆) or carbon dioxide (CO₂).

In the spark switch of the invention, as illustrated in Figures 6 and 7, the surface area of the exposed electrodes is significantly increased by having an inner electrode 102, nested in, or surrounded by, an outer electrode 120. This nested configuration enables the exposed electrode surface area of inner electrode 102 and outer electrode 120 to have up to
5 approximately five times the exposed electrode surface area of conventional axial-spark switches of the same overall volume.

The spark switch of the present invention also allows scaling to large electrode areas at constant switch diameter, without increasing the forces on tie rods 150. Increasing the electrode area of the conventional axial-switch requires increasing switch diameter, which
10 causes higher stresses on the tie rods 150.

Figures 6 and 7 show a spark switch 101, 301, respectively, with end terminals 110, 111 connected to conductors 115, 116, at a first end plate 140 and a second end plate 162 of the switch respectively. The conductors 115, 116 enable the switch to be connected to an electrical power source (not shown) and an electrical load (not shown). The end plates can be
15 made from steel, aluminum, or any strong conducting material. The first end plate 140 is affixed to the second end plate 162 via a plurality of tie rods 150 extending longitudinally between the first end plate 140 and the second end plate 162 of the switch 101. The tie rods 150 may be made from strong-dielectric materials, such as nylon, fiberglass, or lexan (polycarbonate), which enables the tie rods 150 to securely hold the first end plate 140 and
20 second end plate 162 together.

Current is passed through the terminal at the first end plate 140 that causes the switch to produce a spark breakdown current. The spark breakdown current flows from the inner electrode 102 to the outer electrode 120, across a gap 310 formed by the inner electrode 102 being nested in the outer electrode 120. The spark breakdown current is typically between
25 1,000 Amperes and 500,000 Amperes. The electrodes are nested such that the gap 310 is formed between the overlapping electrode surfaces. This gap 310 provides a path for the current to flow and may include air or other gas dielectrics such as sulfur hexafluoride (SF₆), carbon dioxide (CO₂), etc.

An insulating barrier 130 of rigid insulating material provides a pressure container for
30 the spark switch, support for the electrodes and maintains electrical separation of the electrodes. The insulating barrier 130 may be hollow and may extend any portion of the length of the electrodes 102, 120. The composition of the insulating barrier 130 may be

plastic, ceramic or any other material that has heat resistant and flame retardant properties. A preferred material is glass reinforced aliphatic resin as it is strong and char-resistant.

Outer electrode 120 comprises an electrically conductive material, such as brass, tungsten-copper alloy or high-strength carbon. A suitable material for the electrode is one that erodes uniformly and smoothly. The outer electrode 120 has an inner wall 170 and an outer wall 171. Outer electrode 120 has a terminal end portion opposite the second end plate 162. The inner wall of the outer electrode 170 forms a longitudinal cavity of sufficient size to receive, in a mating fashion, the inner electrode 102.

The inner electrode 102 is made of an electrically conductive material, similar to the outer electrode 120, and inserted into the terminal end portion of the outer electrode 120, as shown in Figures 6 and 7. The inner electrode 102 is secured at one end to the first portion of the switch 140, and has a terminal end portion opposite the secured end. The inner electrode 102 has an outer wall 172.

The inner wall of the outer electrode 170, and outer wall of the inner electrode 172, define a radial gap region that provides a channel for spark breakdown current between the inner electrode 102 and outer electrode 120.

The radial gap region 310 may be comprised of air or any other composition that provides a medium for spark breakdown current to flow between the inner and outer electrodes 102, 120. The radial gap 310 may be between approximately 0.001 inch and 1 inch, preferably approximately 0.25 inches. The gap depends on the voltage present in the switch.

A formula that describes the general behavior of spark gap switches as a function of gas species, gap length, and gas density is given as equation 1.

(1)

$$V = k p d + \beta (p d)^{1/2}$$

where V is the switch breakdown voltage, p is the gas density, d is the gap length, and k and β are constants depending on the type of gas. For example if p is the density in atmospheres and d is in millimeters, for air, k is 2.45 and β is 2.1. For sulfur hexafluoride (SF_6), another frequently used gas, k is 6.8 and β is 7.5. This formula and graphs showing deviations from the formula are given in D.Legg, "Insulation Applied to Circuit Breakers," Power Circuit Breaker Theory and Design, Chapter 12, Edited by C.H. Flurscheim.

There is a terminal gap 410 that is formed between the terminal end portion of the outer electrode 120 and the terminal end portion of the inner electrode 102. The terminal gap

410 needs to be large enough to prevent a short circuit situation in the switch in the event of debris accumulation. The terminal gap may range from between 1 to 15 times the magnitude of gap 310.

As shown in Figures 6 and 7, a second terminal gap 420 is formed at the end of the switch opposite the first terminal gap 410. This second terminal gap 420 also prevents a short circuit situation in the switch. It has a similar range in size as the first terminal gap 410.

The terminal gaps 410, 420 tend to collect debris that accumulates during switching. Fluid, either gas or liquid, or a combination of both, can be injected through an inlet port 414 forcing debris out of the switch through outlet port 415 thereby preventing accumulated debris from decreasing the operational life of the switch 101. The inlet port 414 has a cover 415 that can be closed when there is no fluid being injected into the switch 101. Outlet port 415 also has a cover 416 that covers outlet port 416 when there is no fluid being injected into the switch 101.

An advantage of the present spark switch design is improved cleanliness of the insulating barrier 130. The placement of the outer electrode 120 over the inner electrode 102 acts to shield the insulating barrier material 130 from debris produced by switching activity. During switching, spark breakdown currents flow from the inner electrode 102 to the outer electrode 120 that produce ultra-violet radiation and molten and solid by-products which tend to contaminate and degrade the insulating barrier material 130. The present inventive design prolongs the useful life of the insulating barrier 130 because the outer electrode 120 forms a sleeve-like barrier such that the insulating barrier 130 is not exposed to the by-products and debris that result from the arcing currents produced when switching activity occurs.

Figure 7 shows the spark switch 301 with elongated cylindrical electrodes 102, 120. The operational life of the switch 301 can be increased by further increasing the surface area of the electrodes 102, 120. This is accomplished in one embodiment by increasing the length of the inner and outer electrodes 102, 120 along their longitudinal axes. The length of both the inner electrode 102 and outer electrode 120 is increased, which therefore increases the exposed surface area of the electrodes. The second end plate 162 in this elongated embodiment has a cavity that permits the nested electrodes 102, 120 to extend beyond the second end plate 162.

As shown in Figure 7, the inner electrode 102 may be a hollow cylinder with electrode plates on the exterior of the cylinder.

The elongated electrode design as depicted in Figure 7 has the additional advantage that the larger surface area provides increased dissipation of heat generated during spark breakdown current flow.

Figure 8 shows a cross-sectioned view of the spark gap switch. The gap 310 is
5 disposed between the nested electrodes 102, 120.

Figure 9 shows that there can be multiple nested electrodes. Electrode surface 105 is connected to the outer electrode 120 and nested within the inner electrode 102. The electrode 105 and inner electrode 102 are spaced to form a second radial gap 305. This second radial gap 305 conducts current in the same manner as gap 310. This configuration provides
10 multiple electrode surfaces for switching. These multiple electrodes 102, 105 and 120 serve to further increase exposed electrode surface area and thereby increase the operational life of the switch 101.

Figure 10 shows a coaxial embodiment of the spark switch 601. This embodiment does not require endplates but rather, has a connector 615 connected to an electrical power
15 source (not shown) and a connector 616 connected to a load (not shown). Also, there is a conducting outer shield 635, which envelops the inner 600 and outer 620 electrodes. The coaxial embodiment of Figure 10 has a means such as threads, 655 to retain the insulator material 630. There is a gas filled pressurized region 622. A gap 609 is formed between the inner 600 and outer 620 electrodes. There are insulating retainer end plugs 654 and 656 that
20 support the electrodes 600 and 620. These retainer end plugs 654, 656 may be made from, for example, polycarbonate.

Figure 11 shows the coaxial spark switch 701 with the electrodes 700, 720 contained inside a conducting tube 770 that provides a return path for current to pass from a load 775
back to a voltage source 780. The outer electrode 720 is connected to the voltage source 780
25 via a coaxial connector 719. The inner electrode 700 is connected to the load 775 via coaxial connector 718. The coaxial connectors 718, 719 include an inner conductor material 717, 714 respectively. The inner conductive material 717 connects to switch connector 716 and inner conductive material 714 connects to switch connector 715. This embodiment enables electromagnetic fields generated by the switch to be completely contained within the
30 conducting tube 770. This containment reduces switch inductance, lowers system inductance and reduces electromagnetic noise produced by faster switching capability.

The operating environment of the switch dictates the preferred construction materials. For example, electrode construction using a high density electrically conductive material, such as a copper tungsten matrix, (10% to 30% copper is usual with the remainder tungsten) will provide an increased operational life, but will also increase the mass of such a switch compared to the mass of a switch constructed from a less dense material. A high density material erodes more slowly.

In an environment that requires a very high pulse repetition rate, such as 1000 Hz, which puts additional heat stress on the insulating barrier, a ceramic insulating material might be preferable over a plastic insulating material. Additionally, the use of a rigid material as an insulating barrier might be preferable in some operating environments.

While the inner and outer electrodes have been depicted as cylinders, the electrodes are not limited to round dimensions but also encompass electrodes of any shape that are suitable for providing an enclosure such that a gap in which spark breakdown current may pass between the electrodes is formed.

It is apparent that there has been provided in accordance with the present invention a pulsed corona discharge apparatus that fully satisfies the objects, means and advantages set forth hereinabove. While the invention has been described in combination with embodiments thereof, it is evident that many alternatives, modifications and variations will be apparent to those skilled in the art in light of the foregoing description. Accordingly, it is intended to embrace all such alternatives, modifications and variations as fall within the spirit and broad scope of the appended claims.

IN THE CLAIMS:

1. A reactor for treating a contaminated fluent, said reactor having a
5 power supply section (12) and a reactor section (10) characterized by:
said power supply section (12) being capable of providing intermittent
pulses of high voltage to an electrically conductive header (14) of said reactor section (10);
and
said reactor section (10) including said electrically conductive header
10 plate (14),
a plurality of first electrodes (16) electrically interconnected to said
header plate (14),
a plurality of second electrodes (22), each of said second electrodes
(22) being concentrically disposed about one of said first electrodes (16) to define a plurality
15 of reaction chambers to receive contaminated fluent (40),
an electrically conductive reactor plate (20) electrically interconnected
to said plurality of second electrodes (22) and electrically isolated from both said header plate
(14) and said plurality of first electrodes (16),
a manifold (36) circumscribing said header plate (14) and said reactor
20 plate (20) forming a gas receiving cavity (34),
an inlet (42) for delivering contaminated fluent (40) to said gas
receiving cavity (34), and
an outlet (58) to recover remediated fluent (54) from downstream ends
of said plurality of second electrodes (22).

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2. The reactor of claim 1 characterized in that said plurality of first
electrodes (16) are each under tension applied by a combination of said header plate (14) and
an electrically conductive tension plate (64), said plurality of second electrodes (22) being
disposed between said header plate (14) and said tension plate (64).

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3. The reactor of claim 2 characterized in that said plurality of first
electrodes (16) are wires with a diameter of from about 0.001 inch to about 0.1 inch.



4. The reactor of claim 3 characterized in that said plurality of second electrodes (22) are tubular and have an inside diameter of from about 0.5 inch to about three inches.

5 5. The reactor of claim 4 characterized in that said intermittent pulses are at a voltage of between about 10 kilovolts and about 200 kilovolts.

6. The reactor of claim 5 characterized in that electrical contact between said header plate (14) and said reactor plate (20) is by a detachable contact.

10

7. The reactor of claim 6 characterized in that electrical contact between said header plate (14) and said reactor plate (20) is by a compression spring (76).

8. The reactor of claim 6 characterized in that a dielectric is disposed
15 between and bonded to both said header plate (14) and said reactor plate (20).

9. The reactor of claim 8 characterized in that said dielectric is a polymer having a thickness of from about 0.25 inch to about two inches.

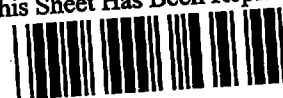
20 10. The reactor of claim 8 characterized in that said power supply system (12), includes:

a connection from a supply of alternating current (78) to a high voltage power supply unit (80) that converts said alternating current to a direct current voltage of in excess of 10 kilovolts;

25 a control unit (79) for intermittently conducting said alternating current to said high voltage power supply unit (80);

a feedback loop (99) between said high voltage power supply unit (80) and said control unit (79) to synchronize said high power supply unit (80) with a high speed switch (88) whereby said high voltage power supply unit (80) is off when said high speed

30 switch (88) discharges;



said high speed switch (88) electrically interconnecting said high voltage power unit (80) and said header plate (14) when discharging and electrically isolating said high voltage power unit (80) from said header (14) at other times;

an isolation resistor (86) connected between said high voltage power supply unit (80) and said high speed switch (88); and

a capacitor (90) connected between said isolation resistor (86) and said high speed switch (88).

11. The reactor system of claim 10 further characterized by a feedback loop (161) between said control unit (79) and a sensor (58) coupled to said remediated fluent (54) that determines a level of hazardous compounds in said remediated fluent (54).

12. The reactor of claim 11 characterized in that said feedback loop (161) is in communicating relationship with a restrictor (160) to adjust the flow rate of said remediated fluent (54) thereby regulating a time for treatment of said contaminated fluent (54).

13. The reactor of claim 11 characterized in that said feedback loop (161) is in communicating relationship with said control unit (79) to adjust power provided by said intermittent pulses of high voltage.

14. The reactor of claim 12 characterized in that said feedback loop (161) is also in communicating relationship with said control unit (79) to adjust power provided by said intermittent pulses of high voltage.

15. A power supply system (12), characterized by:
a connection from a supply of alternating current (78) to a high voltage power supply unit (80) that converts said alternating current to a direct current voltage of in excess of 10 kilovolts;

a control unit (79) for intermittently conducting said alternating current to said high voltage power supply unit (80);



a feedback loop (99) between said high voltage power supply unit (80) and said control unit (79) to synchronize said high power supply unit (80) with a high speed switch (88) whereby said high voltage power supply unit (80) is off when said high speed switch (88) discharges;

5 said high speed switch (88) electrically interconnecting said high voltage power unit (80) and said header plate (14) when discharging and electrically isolating said high voltage power unit (80) from said header (14) at other times;

 an isolation resistor (86) connected between said high voltage power supply unit (80) and said high speed switch (88); and

10 a capacitor (90) connected between said isolation resistor (86) and said high speed switch (88).

16. The reactor of claim 10 or 15 characterized in that said high speed switch (88) is a spark gap switch.

15

17. The power supply system of claim 16 characterized in that said resistor (86) has a resistivity effective to electrically isolate a transformer (80) from said spark gap switch (88).

20

18. The power supply system of claim 16 characterized in that said resistor (86) has a resistivity in excess of about 20 ohms.

19. The power supply system of claim 16 characterized in that said capacitor (90) discharges at an energy charge in excess of about 0.05 joule.

25

20. The power supply system of claim 19 characterized in that said spark gap switch (88) comprises a first electrode (92) electrically connected to said capacitor (90) and a second electrode (96) electrically connected to said power supply electrode (72) with a gap (94) disposed therebetween, said gap (94) filled with a gas.

30

21. The power supply system of claim 20 characterized in that said gas is hydrogen.



22. The power supply system of claim 21 characterized in that said high speed switch (88) provides an interval between pulses of from about 100 microseconds to about one second.

5 23. A switch (101) characterized by:
a first connector (115);
a second connector (116);
inner (102) and outer (120) electrodes disposed between said first
connector (115) and said second connector (116);



10 the inner electrode (102) comprises:

a proximal end;
a terminal end opposite said proximal end; and
an outer wall (172); and

the outer electrode (120) comprises:

15 a proximal end;
a terminal end opposite said proximal end; and

said outer electrode (120) defines a cavity for receiving at least a portion of the inner
electrode (102), and the outer wall (172) of the inner electrode (102) and the cavity of the
outer electrode (120) form a radial gap (310).

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24. The switch (101) as described in claim 23, further characterized by:
an insulating material (130) disposed around the outer electrode (120).

25 25. The switch (101) as described in claim 24, characterized in that the
insulating material (130) is ceramic.

26. The switch (101) as described in claim 24 characterized in that the
outer electrode (120) forms an outer shield surrounding the inner electrode (102).

30 27. The switch (101) as described in claim 23 characterized in that there is
a third electrode surface (105) nested within the inner electrode (102) forming a second radial
gap (305) between said third electrode (105) and said inner electrode (102).

28. The switch (101) described in claim 23 characterized in that the radial gap (310) distance is based upon the voltage applied between the inner (102) and outer (120) electrodes.

5 29. The switch (101) as described in claim 28 characterized in that the radial gap (310) may be from approximately 0.001 inch to approximately 1.0 inch in size.

30. The switch (101) as described in claim 29, further characterized by:
a terminal gap (410) between the terminal end portion of the outer electrode (120) and
10 the terminal end portion of the inner electrode (102).

31. The switch (101) as described in claim 30 characterized in that the terminal gap (410) ranges in magnitude from approximately 1 to 15 times the magnitude of the radial gap (310).

15

32. The switch as described in claim 23, further characterized by:
a first end plate (140) between the first connector (115) and the electrodes (102, 120);
and
a second end plate (162) between the electrodes (102, 120) and the second connector
20 (116).

33. The switch (101) as described in claim 32 characterized in that at least one of the end plates (140, 162) has an inlet port (414).

25 34. The switch (101) as described in claim 32 characterized in that at least one of the end plates (140, 162) has an outlet port (415).

35. The switch (101) as described in claim 32 characterized in that the second end plate (162) has a radial opening for receiving a portion of the outer electrode
30 (120).



36. The switch (101) as described in claim 35 characterized in that the inner (102) and outer (120) electrodes are substantially cylindrical in shape.

37. A method for increasing the operational life of a spark switch
 5 characterized by:
 providing an outer electrode (120) having a terminal end;
 providing an inner electrode (102) having a terminal end;
 nesting the inner electrode (102) inside a cavity of the outer electrode (120) such that a radial gap (310) is formed between the inner (102) and outer (120) electrodes for spark breakdown current and a terminal gap (410) is formed between the
 10 terminal end of the outer electrode (120) and the terminal end of the inner electrode (102).

38. The method as described in claim 37, further characterized by:
 disposing an insulating material (130) in a sleeve-like configuration
 15 around the outer electrode (120).

39. The method as described in claim 38, further characterized by:
 nesting a third electrode (105) within the inner electrode (102) thereby forming a second radial gap (305).

20

40. A coaxial switch (701) characterized by:
 an inner electrode (700);
 an outer electrode (720) having a cavity for receiving at least a portion of the inner electrode (700) in a mating fashion, whereby a radial gap (609) is formed
 25 between the inner electrode (700) and outer electrode (720);
 a conducting tube (770) surrounding the inner (700) and outer electrodes (720);
 a first coaxial connector (718) for coupling one of the electrodes (700) to an electrical load (775); and
 30 a second coaxial (719) connector for coupling the other electrode (720) to an electrical source (780).

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41. The switch (601) according to claim 40 further characterized by:
a first insulating material (654) disposed around a portion of the inner electrode (600) between the inner electrode (600) and the conducting tube (770) whereby the inner electrode (600) is insulated from the conducting tube (770); and
- 5 a second insulating material (656) disposed around a portion of the outer electrode (620) between the outer electrode and the conducting tube (770) whereby the outer electrode (620) is insulated from the conducting tube (770).



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