United States Patent [19]

De Gaston

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[45] **Jan. 8, 1974**

[54] **STATIC DECHARGER**

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[73] Assignee: **McDonnell Douglas Corporation,** Santa Monica, Calif.

[22] Filed: **Apr. 17, 1972**

[21] Appl. No.: **244,698**

[52] **U.S. Cl.** ..... **317/2 R,** 317/2 J

[51] **Int. Cl.** **H05f 3/02**

[58] **Field of Search** ..... 317/2 R, 2 J, 3, 317/4; 250/44

[56] **References Cited**

UNITED STATES PATENTS

3,383,560	5/1968	Ginsburg	317/2 J
2,990,350	6/1961	Natbin	250/44 X

OTHER PUBLICATIONS

Electrostatics in the Petroleum Industry – edited by A. Klinkenberg, Elsevier Publishing Co., 1958, pp. 73–74.

A.P.C. Application of Peycelon et al., Ser. No. 376,930, Published May 25, 1943.

Primary Examiner—J. D. Miller

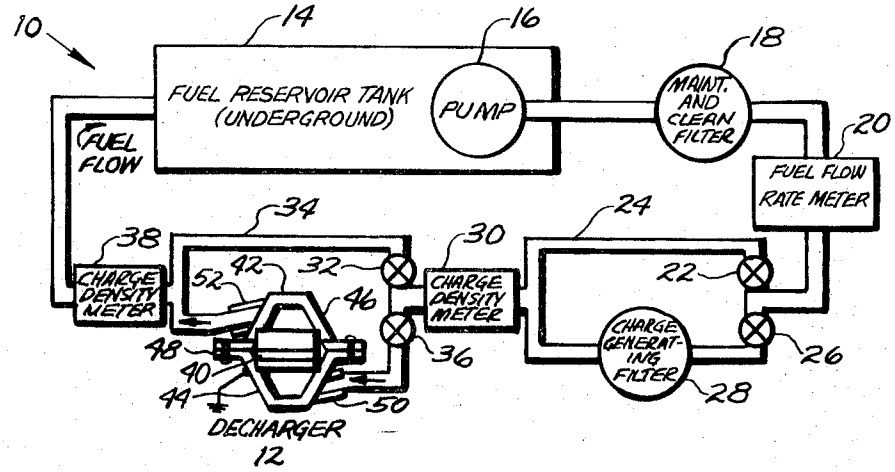
Assistant Examiner—Harry E. Moose, Jr.

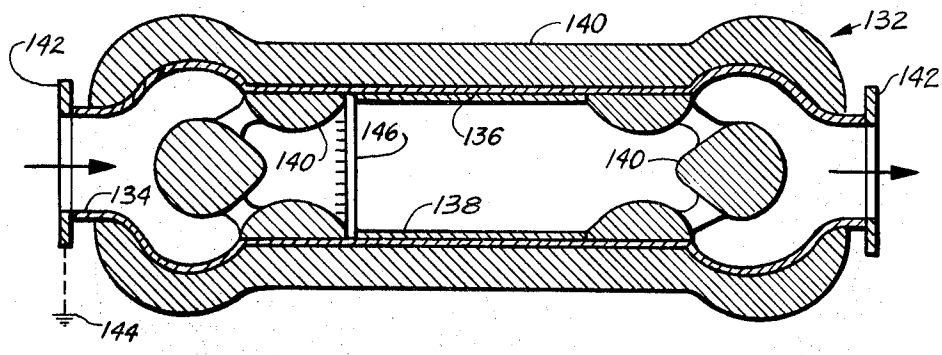
Attorney—Walter J. Jason et al.

[57] **ABSTRACT**

Electrostatically charged nonconducting fluid is rendered temporarily conductive by subjecting the fluid to ionizing radiation of selected radioactive material. Ion pairs are created by the radiation and a predetermined density of ions is produced whereby the fluid is made sufficiently conductive so that it practically cannot hold a charge. While conductive, any acquired charge is free to drain to ground. A volume ionizing embodiment of the invention includes radioactive material disposed in a grounded grating configuration through which the fluid flows and is ionized, and any fluid charge is largely drained to ground through the grating. In another version of the invention, a laminar ionizing embodiment includes radioactive material disposed in a sleeve configuration through which the fluid flows and an adjacent layer of fluid having an opposite charge to its fluid core is produced, and charge neutralization is achieved by subsequent mixing of the fluid layer and core.

18 Claims, 11 Drawing Figures





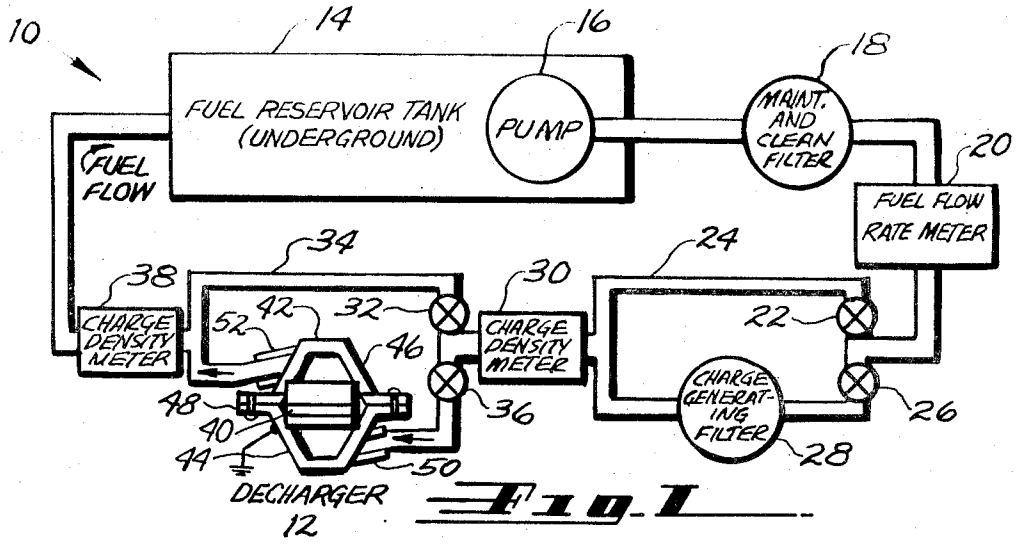


Fig. 1

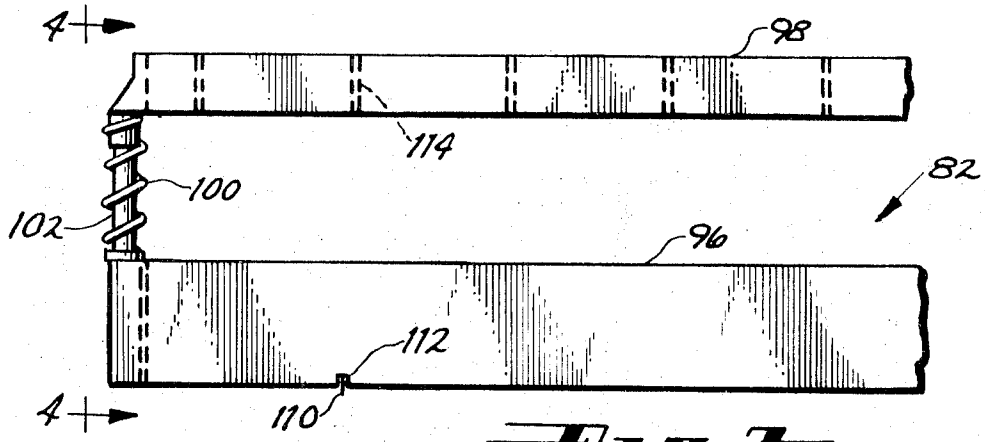


Fig. 3

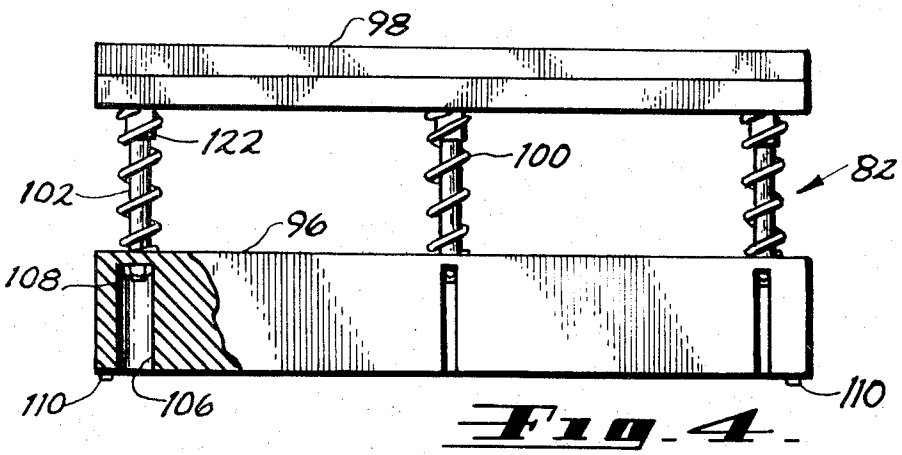


Fig. 4

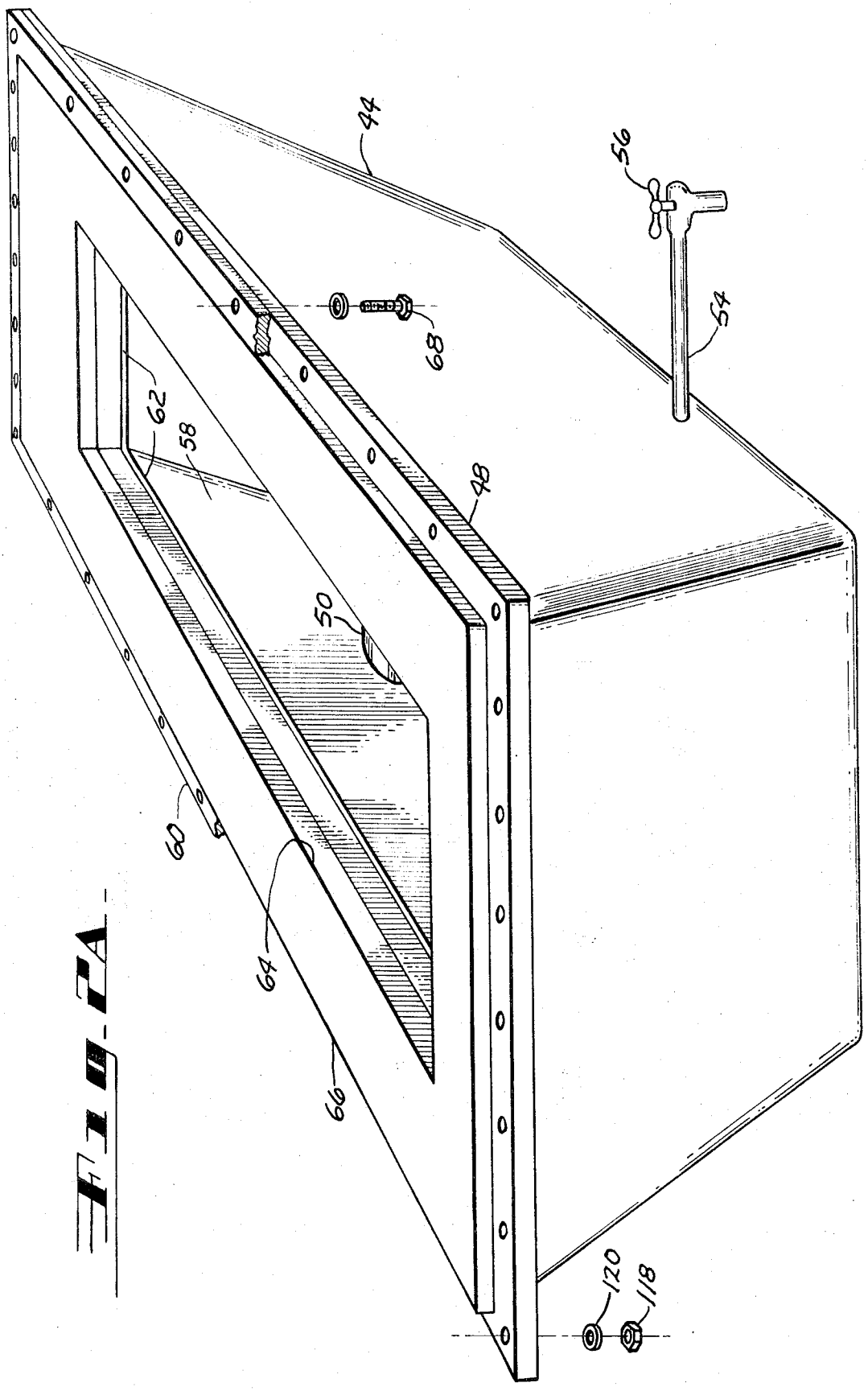


FIG-2A

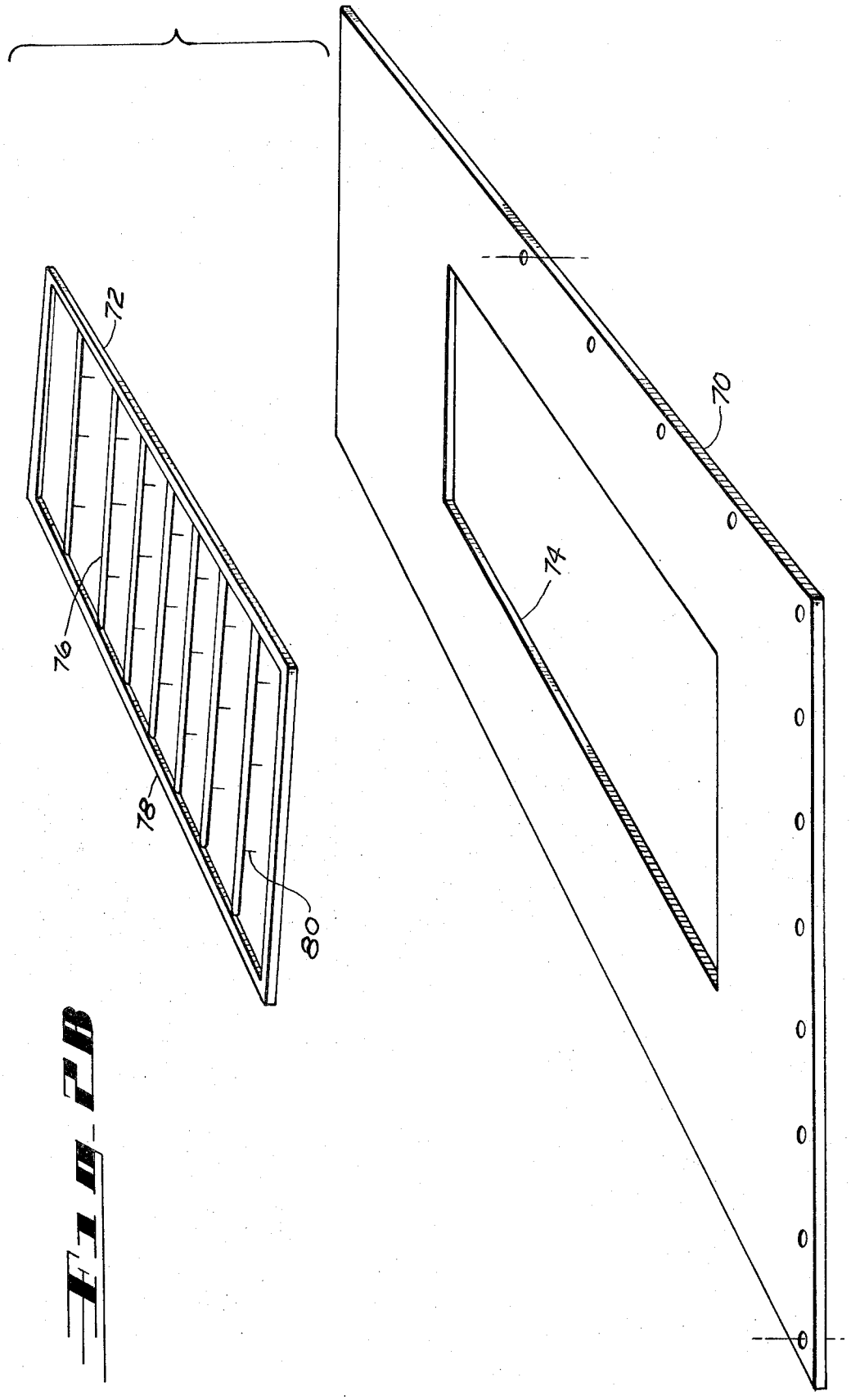


FIG. 2B

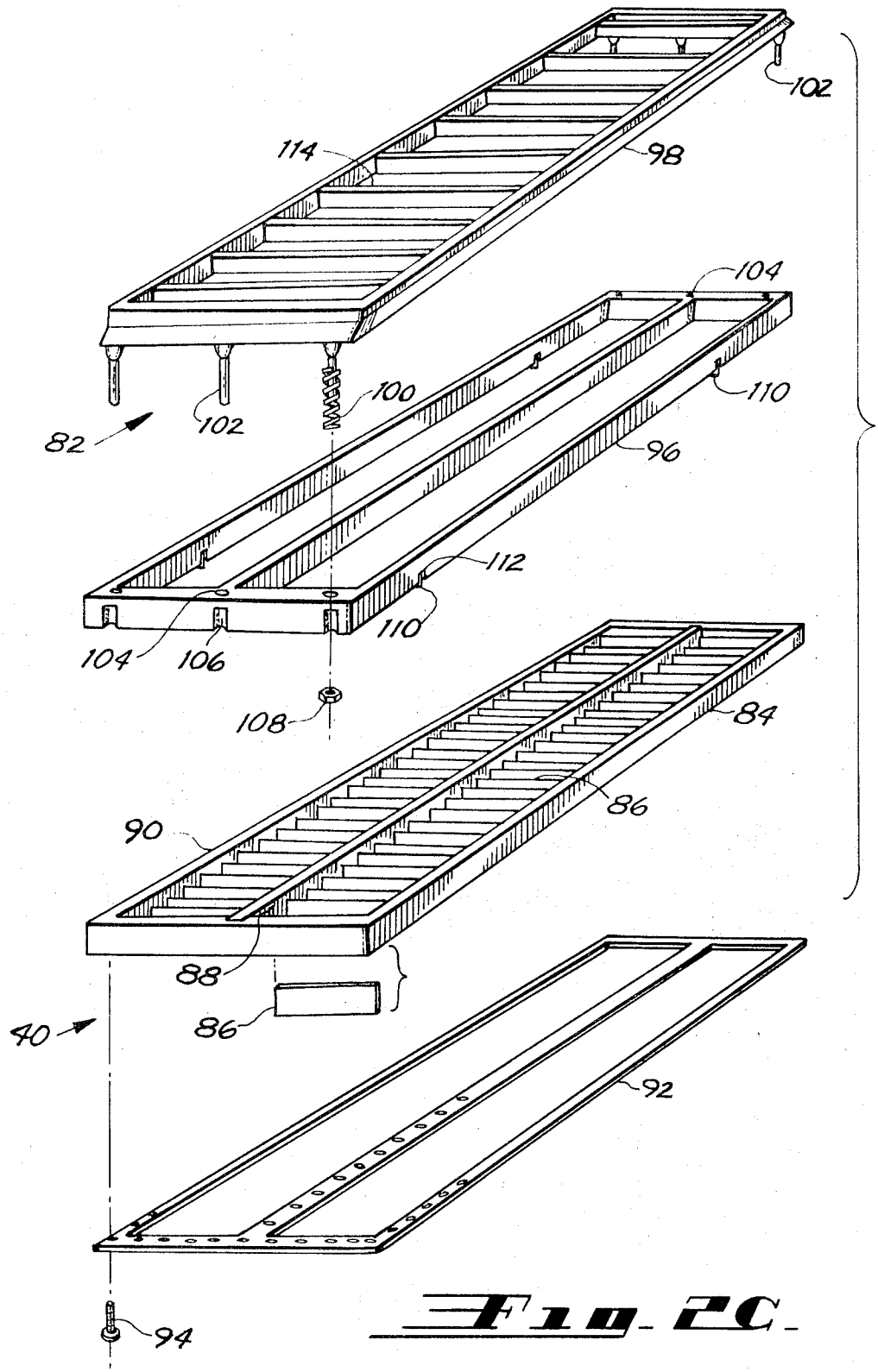

102
114
98
104
100
110
82
102
96
112
110
104
106
108
84
86
90
88
86
40
92
94

Fig. 2C

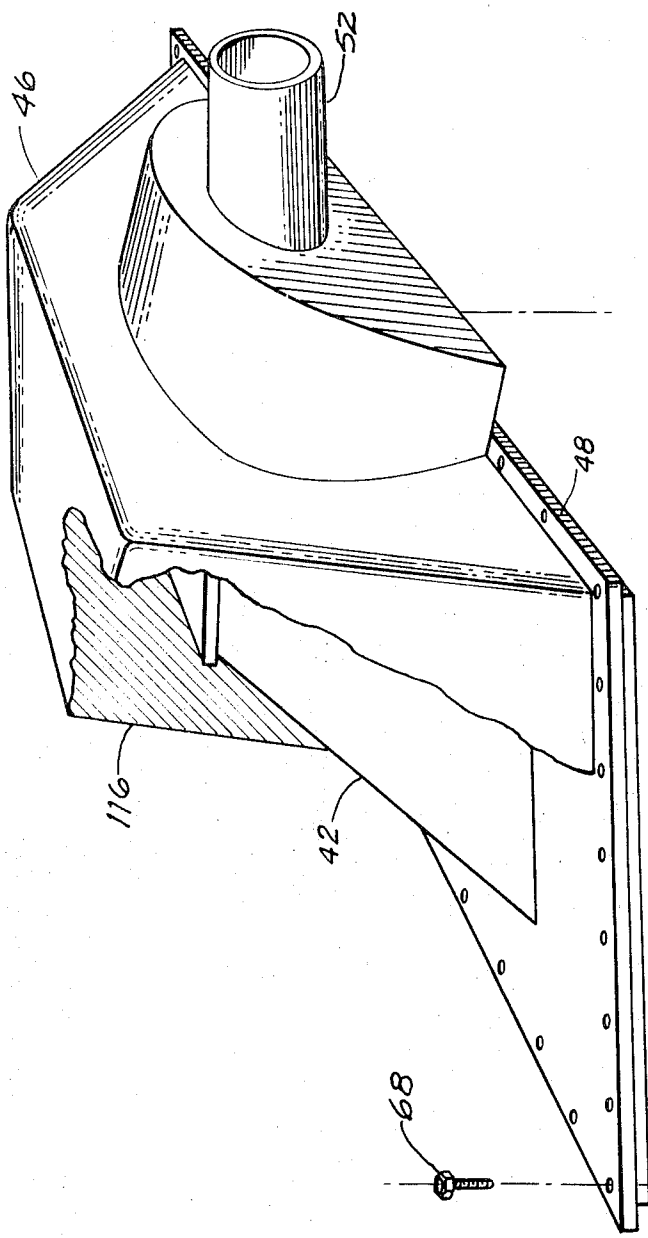


FIG. 7D

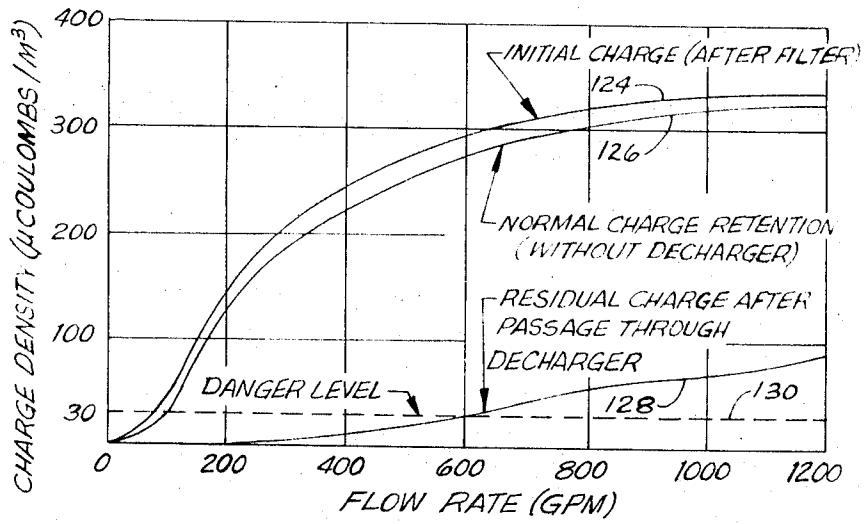


Fig. 5

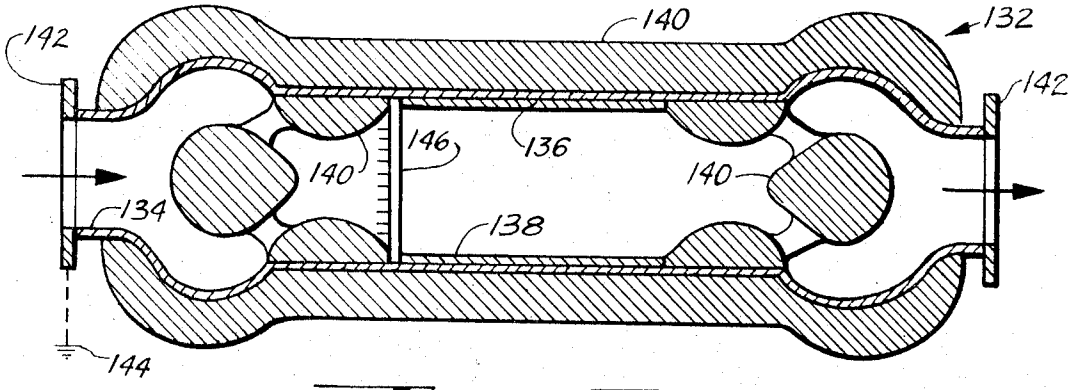


Fig. 6

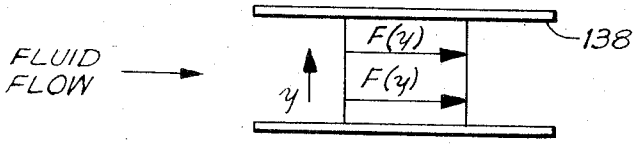


Fig. 7A

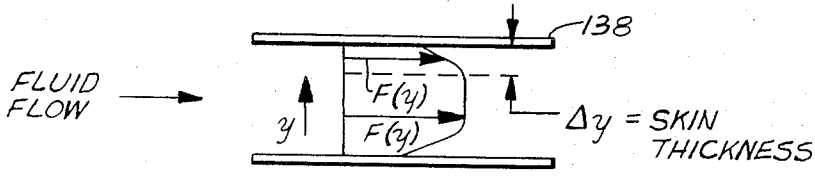


Fig. 7B

STATIC DECHARGER

BACKGROUND OF THE INVENTION

My invention pertains generally to the field of electrostatic charge reduction in variously charged substances. More particularly, the invention relates to a novel means and process of neutralizing electrostatic charges in an electrically charged fluid (gas, liquid or vapor) by the use of nuclear radiation.

The problems caused by static electricity in and on various substances are well known. The problem of reducing electrostatic charges in flammable liquids quickly and surely to a safe level is, of course, a particularly serious one. A discussion of the nature of the problem, and of different methods and devices for removal of electrostatic charges from flammable liquids is, for example, presented in U.S. Pat. No. 3,383,560 of Irwin Ginsburgh for Method and Apparatus for Neutralizing Electrostatic Charges in an Electrically Charged Liquid, patented May 14, 1968. The method and apparatus shown, described and claimed by Irwin Ginsburgh avoid certain of the shortcomings of the earlier methods and devices, and are presently in widespread use throughout the petroleum and distillate (gasoline, jet fuel, etc.) industries.

The apparatus claimed by Irwin Ginsburgh functions under a method which works on the charge injection principle. Briefly stated, a high voltage is developed by flowing a charged liquid through a tubular capacitor comprising an inner nonconductive dielectric of high resistivity and low dielectric constant and a grounded conductive outer plate, and as the charged liquid flows through the capacitor it contacts a plurality of spaced, sharply pointed, grounded electrodes which inject charges of opposite sign into the liquid to neutralize its charge. Among the difficulties encountered with such apparatus was that while at times it would remove 95 percent or better of the charge, this maximum effectiveness was reached only after about 1/2 to 1 ½ minutes, under varying circumstances, of liquid flow. Furthermore, often as little as 15 to 50 percent of the charge was removed from the liquid. It was found that even slight contamination of the inner dielectric surface due to some impurities deposited thereon by the liquid greatly degrades the performance of the apparatus. In addition, attempts at scaling this apparatus down to a smaller physical size reduced its optimum performance capability of charge removal to a maximum of about 75 to 80 percent, and this was reached in certain specific tests only after approximately 5 minutes.

The use of nuclear radiation for neutralizing electrostatic charges on a moving substance has been known for a very long time. Such use, however, has been with fibrous materials and tape, for example, as exemplified by U.S. Pat. No. 1,154,127 of Paul Rasehorn and Gustav Grossman for Apparatus for Neutralizing Electric Charges in Fibrous Materials, patented Sept. 21, 1915 and U.S. Pat. No. 2,264,683 of Donald W. Smith for Method of and Means for Neutralizing Electrostatic Charges on Moving Tapes and the like, patented Dec. 2, 1941. In these instances, the radiation serves to ionize the adjacent air which then functions to remove or neutralize the charges on the moving substance. In spite of the long period of time that nuclear radiation has been used for neutralizing electrostatic charges on different substances, the adjacent air has always been ionized for the purpose of removing the charge.

Throughout this long period, there has been no known or successful direct application of nuclear radiation to ionize a charged substance itself (particularly a liquid) and thereby neutralize the same.

SUMMARY OF THE INVENTION

Briefly, and in general terms, my invention is preferably accomplished by subjecting an electrostatically charged but inherently nonconducting fluid (which can be a gas, liquid or vapor or a fluid carrying solid particles, etc.) to ionizing radiation of a selected radioactive material to creat ion pairs so that a predetermined density of ions is produced whereby the fluid is temporarily rendered sufficiently conductive and practically cannot hold a charge and, while conductive, any acquired charge in the fluid is allowed to drain to ground. Means for performing the above process is provided to decharge a fluid. As used herein, "decharge" means the removal of charge from a fluid and "discharge" means the expelling of the fluid itself, as from a pipe or into a tank.

A fluid volume ionizing embodiment of the invention includes radioactive material disposed in a grating configuration through which the electrostatically charged fluid flows and is ionized. The radioactive material can be suitably encased in metallic strips, and these radioactive strip elements are mounted in discretely spaced relationship within a frame to provide a grating configuration. This grating is installed in a suitably shielded housing through which the fluid flows. The housing is grounded, and the plane of the grating is positioned therein at approximately right angles to the general direction of fluid flow therethrough. The configuration of the radioactive elements and their spacing within their mounting frame are selected to produce a sufficient density of ions throughout the entire volume of the fluid flowing at any rate in a given range of flow rates through the grating. The fluid is thus rendered sufficiently conductive so that any acquired charge therein can be rapidly relaxed or drained to ground.

Ground is provided by the housing and also normally by the grating which is preferably installed with good electrical contact to the grounded housing. A good contact is, for example, obtained through a box spring assembly positioned between the grating and the housing. The box assembly illustratively includes a lower base frame and an upper ground grid which is supported on the base frame and is spring biased therefrom. The base frame preferably mounts a few, short, sharp blades which can cut into the upper surface of the grating to obtain a good electrical contact therewith, and the upper grid is positively attached to the upper half of the grounded housing. The box assembly is located downstream of the grating and provides added mechanical strength thereto. The ground grid structure assists in the control of fluid flow and provides more conductive surface for removal and neutralization of any remaining ions and charges in the fluid if still present at that point. It is noted that the ground grid is not essential or even really necessary under normal conditions, and can be omitted from the volume ionizing embodiment of the invention if desired.

Similarly, the volume ionizing embodiment can optionally include a charge extractor located upstream of the radioactive grating to reduce any exceptionally high charge level (in excess of 300 microcoulombs/cubic meter, for example) in the fluid to a

lower one before reaching the grating. The extractor can include a series of needle bars secured in parallel and spaced relationship within a frame corresponding in size and shape generally to the grating frame. The extractor is installed in good contact to the grounded and shielded housing with the plane of the extractor frame positioned therein at approximately right angles to the general direction of fluid flow therethrough. Each needle bar mounts a few spaced, sharply pointed, electrodes which are oriented perpendicularly to the plane of the extractor frame. The extractor is preferably installed in the housing so that its electrodes (needles) point upstream.

Another version of the invention includes a laminar ionizing embodiment wherein radioactive material is disposed in a sleeve configuration through which the fluid flows. A cylindrical metallic sleeve encases selected radioactive material therein, for example, and the sleeve is positioned within a longer section of pipe contiguously to its inner surface. The pipe section is suitably shielded and can be installed as a connecting length of (grounded) piping through which fluid is flowed. This configuration of the invention functions differently from the grating configuration in that positively charged fluid flowing in the pipe induces a negative charge on such pipe, then when the fluid flows over the radioactive sleeve, the induced charge effectively moves onto a laminar layer of fluid adjacent and concentric to the sleeve, and charge neutralization is subsequently achieved downstream by mixing of the fluid layer and its core which have equal and opposite charges.

BRIEF DESCRIPTION OF THE DRAWINGS

My invention will be more fully understood, and other features and advantages thereof will become apparent, from the following description of two exemplary embodiments of the invention. The description is to be taken in conjunction with the accompanying drawings, in which:

FIG. 1 is a schematic block diagram of a test rig setup utilized to test a full scale decharger constructed according to this invention;

FIGS. 2A, 2B, 2C and 2D, together, comprise an exploded view of an illustrative, volume ionizing, embodiment of the invention;

FIG. 3 is a fragmentary front elevational view of a box spring assembly used in the illustrative, volume ionizing, embodiment;

FIG. 4 is a side elevational view, shown partly in section, of the box spring assembly as taken along the line 4—4 indicated in FIG. 3;

FIG. 5 is a graph showing plots of charge density versus fluid flow rate and which depict typical performance of the illustrative, volume ionizing, embodiment of the invention;

FIG. 6 is a central sectional view of an illustrative, laminar ionizing, embodiment of this invention; and

FIGS. 7A and 7B are diagrams illustrating flow velocity profiles of fluids respectively having zero and some viscosity flowing through a sleeve.

DESCRIPTION OF THE PRESENT EMBODIMENTS

In the following description of two exemplary embodiments of my invention and its associated processes, some specific dimensions and types of materials are disclosed. It is to be understood, of course, that such dimensions and types of materials are given as examples only and are not intended to limit the scope of the invention in any manner.

FIG. 1 is a schematic block diagram of a test rig setup **10** utilized to test a full scale decharger **12** constructed according to this invention. The decharger **12** was constructed to decharge Jet-A fuel flowing at a nominal rate of 600 gallons per minute (gpm) and a maximum charge of 300 micro-coulombs/second (u-c/s). In the setup **10**, underground tank **14** has a capacity of about 8,000 gallons of fuel which can be pumped out by pump **16** and circulated through a regular maintenance and cleaning filter **18**, fuel flow rate meter **20**, then through either valve **22** to bypass line **24** or valve **26** to a charge generating filter **28**, through first charge density meter **30**, then through either valve **32** to bypass line **34** or valve **36** to decharger **12**, and through second charge density meter **38** back into the underground tank. Flow rates up to approximately 1,250 gpm are attainable in the setup **10**, the piping is made of 4-inch inside diameter pipe, and 4,000 gallons of Jet-A fuel are used in the recirculating system, for example. The filter **28** is used to simulate actual refueling conditions by charging the fuel to 200 to 300 micro-coulombs/cubic meter (u-c/m^3).

The exemplary decharger **12** basically includes a nuclear irradiator **40** installed in a shielded container **42** wherein the fuel is constrained to flow from the lower half through the irradiator to the upper half of the container. The container **42** is, for example, a steel container formed from bolting lower and upper truncated pyramids **44** and **46** together at their abutting base flanges **48**. The steel is overlaid by a suitable thickness of lead to provide adequate shielding, and the pyramids **44** and **46** have 4-inch inlet and outlet pipes **50** and **52**, respectively, extending through a wall of each pyramid. A wide mesh wire screen (not shown) is installed in each of the pipes **50** and **52** as a precautionary measure to catch any radioactive strip element or other component part of the irradiator **40** in the remote event that any of such items are dislodged or broken loose. The container **42** is, of course, grounded as schematically indicated in FIG. **1**.

There is an electrostatic ignition hazard associated with the handling of jet grade fuels. This hazard is directly related to two attributes of the fuels, which are their low conductivities and their vapor pressures. The former enables the fuels to become charged with sufficient electrostatic energy so as to ignite appropriate fuel vapor-air mixtures. Vapor pressures of fuels in this class at ordinary handling temperatures provide the right fuel-to-air ratio to create a hazardous explosive mixture. Charge build-up can be prevented or significantly reduced by using impure fuel, not filtering the fuel, and/or moving the fuel slowly. The use of impure fuel is objectionable in jet engines, and even "pure" fuel must be purified again before using, thus requiring the use of filters. The economics of fueling large aircraft is, of course, incommensurate with the use of low fuel rates. Filtering produces 10 to 200 times more charge than generally occurs without filtering, and a normal flow rate would not allow enough time for the charge to "leak" off before being concentrated in a receiving tank.

FIGS. 2A, 2B, 2C and 2D, placed adjacently together in an ascending sequential order, comprise an exploded view of the decharger **12**. FIG. 2A is a perspective view

of the lower pyramid **44** which is generally symmetrical to the upper pyramid **46** except that the lower pyramid is additionally provided with a drain line **54** connecting with its interior and having a pet cock **56** at the end of the line. Of course, the inlet pipe **50** is located in a wall **58** opposite to that in which the outlet pipe **52** of the upper pyramid **46** is located. Both lower and upper pyramids **44** and **46** are provided with a lead ring seal **60** which is positioned along the offset base flange **48** as illustrated. Also, a recessed retaining shoulder ledge **62** is provided a short distance within opening **64** below the base surface **66** around the interior walls of both of the pyramids **44** and **46.** A number of bolts **68** can be suitably used to secure the pyramids **44** and **46** together completely around the flanges **48.**

FIG. **2B** is a perspective view of a lead gasket **70** and a charge extractor **72** used in the decharger **12.** The gasket **70** is normally positioned between the base surfaces **66** and ring seals **60** of the lower and upper pyramids **44** and **46** when secured together by the bolts **68.** The gasket **70** has a rectangular opening **74** which corresponds in size to the base surface openings **64.** The extractor **72** includes a series of needle bars **76** affixed in a parallel and spaced arrangement within a frame **78** which fits in and against the retaining shoulder ledge **62** (FIG. **2A**) in the lower pyramid **44** in good ground contact therewith. Each of the bars **76** mounts, for example, three equally spaced and sharply pointed electrodes **80** which extend perpendicularly from the plane of the frame **78.** These electrodes **80** extend approximately 0.5 inch from their mounting bar **76** and can be made from commercially available, stainless steel, sewing needles cut to the necessary length and suitably welded to a mounting bar. Illustratively, there can be seven equally spaced needle bars **76** made of aluminum and affixed in an aluminum frame **78** which is approximately 17 inches long and 8 inches wide. As stated previously, the charge extractor **72** is optional and can be omitted from the decharger **12** if desired.

FIG. **2C** is a perspective view of the nuclear irradiator **40** and a box spring assembly **82** used in the exemplary decharger **12.** The nuclear irradiator **40** is, in this instance, provided in the form of a radioactive grating **84** including a substantial number of radioactive strip elements **86** mounted therein. The elements **86** can be, for example, strips formed from strontium silicate ($^{90}SrSiO_3$) beads or microspheres encapsulated in aluminum (Al) and then covered with a thin layer of stainless steel. The ends of each of the strip elements **86** are installed in a corresponding pair of a number of slots **88** provided in mounting frame **90.** The slots **88** are each approximately 0.1 inch deep, 0.4 inch long and are open at the lower surface of frame **90.** After the elements **86** are installed in the slots **88,** a thin retainer plate **92** is fastened to the lower surface of the frame **90** by screws **94** to secure the elements firmly in place. Each strip element **86** is, for example, 3.75 inches long, 0.4 inch wide and 0.1 inch thick, and the elements are mounted in parallel with a center-to-center spacing between successive elements of 0.4 inch. The peripheral dimensions of the grating **84** and its retainer plate **92** are substantially equal to those of the extractor frame **78,** and the lower peripheral surface of the retainer plate is normally held in contact with the upper peripheral surface of the extractor frame by action of the box spring assembly **82.**

The radioactive strip elements **86** are high integrity beta radiation sources which can withstand severe operating conditions. The 74 strontium-90 elements **86** produced approximately 9,175 curies; however, because of their relatively heavy encapsulation, only about 15 percent energywise or effectively 1,373 curies of the beta activity was available. From this level of radiation, for a nominal fuel flow rate of 600 gpm, at 300 u-c/m^3 and a judiciously estimated ion mobility rate of 0.75×10^{-8} m^2/sec-volt, a relaxation time of approximately 6 milliseconds is obtained in the radioactive grating **84** configuration. The available relaxation time due to (nominal) fuel velocity is about 0.016 sec. Since the range of testing was from about 100 to 1,200 gpm and because of the uncertainty in the value of ion mobility rate and the number of effective ion pairs produced, the difference between the relaxation time and time available is not excessive.

Box spring assembly **82** includes a lower base frame **96** and an upper ground grid **98** which is supported on, for example, six biasing springs **100.** The springs **100** are helical compression springs installed about respective pendent (from the upper grid **98**) pins **102** that extend through guide holes **104** and into displacement channels **106** in the ends of the base frame **96.** Retainer nuts **108** are tightened to the lower ends of the pins **102** and fit within the channels **106.** Four small and sharp blades **110** (razor blade segments) are secured to the lower surface of base frame **96** in respective slots **112** with a suitable electrical bonding substance. The blades **110** extend approximately 0.06 inch below the lower surface of the base frame **96** and normally cut into corresponding points of the upper surface of the grating frame **90** to obtain good electrical connections therewith. The upper grid **98** is of aluminum and supports, for example, nine aluminum plates or bars **114** which are spaced approximately 2 inches (center-to-center) apart between successive bars. The bars **114** can be approximately 7.68 inches long, 0.75 inch wide and 0.125 inch thick, and can be welded at the ends to the sides of the ground **98.** The grid **98** is generally unnecessary for ion ground usage and its primary function is being part of the box spring assembly **82** which serves mainly as a spring biasing and cushioning device.

FIG. **2D** is a perspective view, shown partially broken away sectionally, of the upper pyramid **46.** As mentioned previously, the pyramid **46** is similar to the lower pyramid **44** (FIG. **2A**) except for minor inconsequential differences. It includes a steel container **42** half with, for example, about 4 inches of lead shielding **116,** outlet pipe **52** (corresponding to the inlet pipe **50** of the lower pyramid **44**) and a lead ring seal **60** (not shown). A number of bolts **68** is used with the nuts **118** and washers **120** shown in FIG. **2A** to secure the lower and upper pyramids **44** and **46** together. In certain areas just opposite to the inlet and outlet pipes, the bolts **68** can be used to engage tapped structural holes where space is unavailable to accommodate the nuts **118** and washers **120.** The relatively thick lead shielding **116** is provided largely because of bremsstrahlung (high energy gamma radiation) formation resulting from high velocity beta particles passing close to (and deflected by) nuclei.

The nuclear irradiator **40** having the grating **84** configuration (FIG. **2C**) provides high fuel volume ionization using beta radiation sources (radioactive strip elements **86**) with a comparatively small bremsstrahlung

formation. Radiations other than beta can, of course, be used to cause ionization of a fluid to render it temporarily conductive. Alpha, beta or gamma radiation, or any combination thereof, can be suitably selected and their sources appropriately arranged to cause optimum ionization of a gas, liquid or vapor, or any combination thereof. The specific ionization of alpha particles is greater than that of beta particles and alpha radiation may, therefore, be preferably used to ionize a gas or mixture of gases where the alpha particle range is sufficient. Gamma radiation has a long range, which introduces a difficult shielding problem in most cases. However, in those cases where large volumes of charged fluids are involved, use of gamma radiation would be optimum to ionize the large volumes since the gamma sources can be located at the centers of such volumes, for example.

FIG. 3 is a fragmentary front elevational view of the box spring assembly **82**. Details of the assembly **82** are more clearly shown here. The lower base frame **96** supports the upper ground grid **98** on biasing springs **100** installed about the pendent pins **102**. Blades **110** are secured to the lower part of base frame **96**, and ground plates or bars **114** are welded between the sides of upper grid **98**. The blades **110** normally cut into the upper surface of the grating frame **90** (FIG. 2C), and the upper surface of the upper grid **98** is held against shoulder ledge **62** (similar to that shown in FIG. 2A) of the upper pyramid **46** (FIG. 2D) with the upper grid suitably attached thereto for a positive ground contact.

FIG. 4 is a side elevational view, shown partly in section, of the box spring assembly **82** as taken along the line 4—4 indicated in FIG. **3**. It can be seen that the pins **102** are fastened (threaded) at their upper ends to collars **122** of the upper grid **98** and to retainer nuts **108** at their lower ends. The biasing springs **100** are installed about the pins **102** and normally urge the nuts **108** to the tops of their respective channels **106**. Blades **110** are located at the sides of the lower part of the base frame **96** as indicated. The box spring assembly **82** basically provides a good ground connection to the radioactive grating **84** (FIG. 2C) from the upper pyramid **46**.

FIG. **5** is a graph showing plots of charge density versus fuel flow rate, which illustrate typical test results of the decharger **12** operating in the test rig setup **10** of FIG. **1**. Curve **124** is a plot of initial fuel charge as measured by the first charge density meter **30** after passing through the charge generating filter **28**. Curve **126** is a plot of normal charge retention by the fuel as measured by the second charge density meter **38** after passing through the bypass line **34**. Curve **128** is a plot of the residual fuel charge as measured by the second meter **38** after passage through the decharger **12**. Broken line **130** indicates a danger level being at 30 u-c/m^3 and this level was achieved as intended by the decharger **12** in reducing an initial charge of 300 u-c/m^3 to such level for a fuel flow rate of 600 gpm.

It is noted that the performance curve **128** was that of the decharger **12** including the charge extractor **72** therein. Tests made without including the extractor **72** in the decharger **12** showed that the extractor had only a negligible effect in achieving the residual charge. Any effect was, in fact, undetectable at the lower flow rates under 600 gpm. The charge extractor **72** is only effective at very high charge densities well in excess of 300 u-c/m^3, for example, and can be omitted from the decharger **12** for ordinary usage. The operation of the nuclear irradiator **40** is the main and essential factor in accomplishing the desired and necessary reduction of charge.

FIG. **6** is a central sectional view of an illustrative, laminar ionizing, embodiment of this invention. A minimum size device **132** of relatively simple construction provides optimum use of radioactive material employed therein. The device **132** can be generally cylindrical in configuration and includes a length of steel pipe **134** having radioactive material **136** encased in a stainless steel sleeve **138** positioned concentrically within the pipe, and lead shielding **140** provided outside and in the ends of the pipe as shown. Flanges **142** are provided at the ends of the pipe **134** to permit easy connection in, for example, a fuel supply line (not shown). The pipe **134** is, of course, normally grounded as schematically indicated by ground connection **144**. A needle extractor **146** generally similar to the charge extractor **72** (FIG. **2B**) can, if desired, be located just upstream of the radioactive sleeve **138**.

Illustratively, the laminar device **132** can be approximately 34.0 inches long and 10.0 inches in (outside middle portion) diameter. The steel pipe **134** has an inside diameter of 6.0 inches and the lead shielding **140** on the pipe can be generally about 1¾ inches thick, for example. The radio-active sleeve **138** can be approximately 10.0 inches long and approximately 0.2 inch thick. The sleeve **138** can be a high integrity source of beta radiation provided by radioactive strontium-90 material and suitable for use in decharging Jet-A fuel flowing through it. For a nominal fuel flow rate of 600 gpm, at 300 u-c/m^3, the sleeve **138** can provide a level of radiation of about 900 curies, for example, in the device **132** for reducing the charge to a safe level. The level of radiation provided can be reduced by a factor as large as **30** with improved and proper control of fluid flow wherein the radially inner core of fluid is suitably controlled to flow at substantially the same speed as the radially outer skin layer thereof.

In operation, it is assumed that electrostatically charged fuel flows into the left end of device **132** and out its right end. Any exceptionally high charge level in the fuel is reduced by the needle extractor **146**. The positively charged fuel has, of course, induced a negative charge on the inside surface of the pipe **134**. When the fuel flows over the radioactive sleeve **138**, an adjacent laminar layer of fuel is rendered conductive so that the induced negative charge moves onto the laminar layer. This negative charge in the laminar layer is equal and opposite to the positive charge in the fuel core so that no further charge is induced on the pipe **134**. The positively charged fuel core is mixed downstream with the negatively charged laminar layer of fuel on leaving the right end of the device **132** and is thereby neutralized. The thickness of the laminar layer of fuel can be, for example, of the order of about 5 to 10 millimeters (mm) for the illustrated device **132**. Of course, if the fuel core is suitably controlled in device **134** by additional vanes or the like, so that the core's speed is close to that of the laminar layer of fuel, the thickness of the latter can be considerably less and, accordingly, a much lower level of radiation would be required.

Basic criteria for designing the static decharger, whether in a total volume irradiator embodiment or the equal but opposite charge embodiment, evolves from

the basic self-relaxation concept as expressed in the following equation,

$$p = p_o \exp [-K_1 t]$$

Eq. 1

where

p_o is the initial charge density at any point inside the fluid medium,

K_1 is a constant dependent upon the characteristics of the fluid medium and the conductivity,

t is the time, and

p is the charge density at any later time t at the point inside the fluid medium.

For the decharger, it can be shown that

$$p/p_o = \exp [-K_2 t^2]$$

Eq. 2

as the fluid conductivity g, which is a factor in the constant K_1, is directly proportional to the time of exposure t (i.e., inversely proportional to the fluid flow velocity).

Now, from the well-known continuity law,

$$-\int_V (\partial p/\partial t) dV = \int_S J \cdot dS = \int_S gE \cdot dS = g \int_S E \cdot dS$$

Eq. 3

where

V is a given fluid volume,

S is the surface enclosing the volume V,

J is the current density at a point where the element of area dS is located, and

E is the electrostatic field due to p.

Therefore,

$$\int_S E \cdot dS = (1/\epsilon) \int p dV = k\epsilon_0$$

Eq. 4

where

ϵ is the permittivity of the fluid medium,

ϵ_o is the permittivity of free space, and

k is the dielectric constant of the fluid medium.

Substituting Equation 4 in Equation 3,

$$-\int_V (\partial p/\partial t) dV = (g/\epsilon) \int p dV$$

$$(\partial p/\partial t) = -(g/\epsilon) p$$

Eq. 5

By integration, then

$$(p/p_o) = \exp [-(g/\epsilon) t]$$

Eq. 6

where g is assumed to anisotropic and equal everywhere in the surface layers. An important principle is noticed that it is the value of g in the outer layers of the fluid volume that determines the current out of (or into) the volume considered.

Of course, if the fluid volume under consideration has non-uniform velocity distribution, then it is essential that each interface in velocity differences has the same g (or a different equation for the relaxation at each interface). Thus, for all practical purposes in this case, it is desirable from a design standpoint to have g approximately constant throughout the volume.

The conductivity g of the fluid in the linear approximation is

$$g = (n^+ M^+ + n^- M^-) e$$

Eq. 7

where n^+ is the density of positive ions, n^- is the density of negative ions, M^+ is the mobility of the positive ions (m^2/sec-volt in the MKS system), M^- is the mobility of the negative ions, and e is the basic unit of electrical charge (1.6×10^{-19} coulomb). It is assumed in Equation 7 that the ions are singly charged. Assuming, in addition; that $n^+ = n^-$ and $n^+ + n^- = n$, $M^+ = M^-$ and $M^+ + M^- = M$, then

$$g = enM$$

Eq. 8

Since the value of e is fundamental and M is a property of the fluid, the one factor in g that can be arbitrarily adjusted is n. Of course, the decharger works on an artificially introduced n much greater than Δn^+ (or Δn^-) where the Δn^+ (or Δn^-) is responsible for the charge on the fluid (fuel).

The density of ions, n, has been made large in the past by the addition of substances that ionize in the fluid (fuel), the so-called anti-stat additives (which permanently alter the fuel). In my invention, n is increased by using high energy radiation to strip electrons from some molecules and deposit them on others. The most practical source of this radiation and radioactive material are, of course, used in this invention. The action of the radiation increases the value of n and is a temporary change since, for all practical purposes, the fluid is left unchanged.

The effect of increasing n and, hence, g is seen from Equation 6. Substituting Equation 8 into Equation 6,

$$(p/p_o) = \exp [-(enM/\epsilon) t]$$

Eq. 9

Thus, a formal treatment yields Equation 9; however, for practical purposes, the fluid is not entirely surrounded by a conductor nor is it practical to irradiate in such a manner because the object is to decharge the fluid and then pass it on and repeat the same to the following fluid.

Some valuable considerations in the static decharger can, however, be raised here in the context of Equation 9. First, t is the time over which the fluid volume is both at elevated n and in contact with a grounding element. Calling the average duration of t, for the root mean square (as will be apparent later) averagely moving volume element, t'.

Then, proportionately

$$t' \propto AL/F$$

Eq. 10

where

F is the fluid flow rate,

A is the mean cross sectional area, and

L is the average length of the radioactive element (width of grating strip elements **86** or length of sleeve **138**, for example).

Second, n is the ion density produced by irradiation. In the case of non-uniform fluid flow (the usual case), it was seen that n should be nearly constant for ease of calculation. This means that the fluid should be uniformly irradiated, or a trade-off between volume uniformity and surface irradiation should be made. Thus, the decharger design now must consider the range of the irradiation in the fluid. In the case of most liquids, beta radiation in the range of 0.5 to 1.5 million electron volts (Mev) average radiation energy is the most practical from the point of range in the liquid, penetration through the radioactive material encapsulation and minimizing the bremsstrahlung radiation against which shielding is most difficult.

Taking the foregoing considerations into account, the preferred (best) embodiment of the decharger accomplishing the process is a grating-like device where the ion recombination time is very short. It is very short, being approximately 0.1 millisecond for the n used in the decharger **12** (FIG. **1**), but increasing as $1/n^2$. In the static decharger, n is of the order of 10^{12} to 10^{14} ions/cc, for example. Let,

$$n = (DI/F') = DIt'/A'L$$

Eq. 11

where D is the activity or number of radioactive disintegrations per unit time, I is the ionization or number of ions produced per disintegration, F' is the flow rate of the irradiated fluid, and A' is the mean cross sectional area of the irradiated part of the fluid. As can be seen, I is a very critical number. There are a number of theories used and experiments conducted to try to predict and measure I. For the decharger **12**, it was theoretically determined on one ion-pair per 100 ev of the beta radiation (or 50 ev per ion). Following actual construction of the decharger **12**, however, it appears more in the range of 350 to 800 ev to produce an ion-pair.

Substituting Equation 11 into Equation 9 and using $t = t'$,

$$(p/p_o) = \exp\,[-eMDI(t')^2/\epsilon A'L]$$
$$= \exp\,[-eMDIA^2L/\epsilon A'F^2]$$

Eq. 12

Thus, Equation 12 is the basic design equation for the static decharger. The dependence on $(t')^2$ or $1/F^2$ is immediately seen. In practice, though, the relationship of F' and I and D to form n is not so simple as given in Equation 11 because of recombinations but, or a rough approximation, Equation 12 works. For volume irradiation, a grating embodiment of suitable geometry appears superior. Of course, for volume irradiation, $A = A'$ and Equation 12 becomes

$$(p/p_o) = \exp\,[-eMDIAL/\epsilon F^2]$$

Eq. 13

Thus, in designing a volume decharger, the specific geometry employed is considered in practice and calculations are accordingly made. For example, to reduce 300 u-c/m^3 to 30 u-c/m^3, $(p/p_o) = 0.1$ and, for a given flow rate F, the product DAL can be used to determine the relative amount of radioactive material and dimensions desired.

FIGS. 7A and 7B are diagrams indicating the flow velocity profiles of fluids respectively having zero and some viscosity flowing through the radioactive sleeve **138**. In FIG. 7A, for a zero viscosity fluid flowing in the sleeve **138**, flow velocity $F(y)$ is seen to be the same for all positions of y. This is the limiting case for a fluid of zero viscosity wherein there is theoretically no skin layer. Of course, this is physically unrealizable. In FIG. 7B, for a fluid having some viscosity flowing in the sleeve **138**, it is seen that to be effective, the skin thickness Δy through which the conductivity is made larger (and quasi-uniform) must be thick enough wherein the radially inner velocity of the skin layer is up to that percentage of the mean flow velocity of the center core portion which is equal to the desired percentage of decharging. This, of course, puts a constraint on beta radiation range so that the mean ionizing range in the fluid of the beta particles must be approximately equal to Δy. In this case, where r is the inner radius of the sleeve **138**,

$$A = \pi r^2$$

Eq. 14

and

$$A' = \pi r^2 - \pi(r-\Delta y)^2$$
$$= \pi[2r(\Delta y) - (\Delta y)^2]$$

Eq. 15

With strontium-90, for example, maximum energy beta range is about 0.43 inch and mean energy beta range is about 0.15 inch. Thus, taking the weighted average of these ranges, Δy is equal to approximately 0.2 inch (which is half the spacing used between radioactive elements **86** of the grating embodiment).

Similarly, for the grating configuration, the range of the beta particles is the determinant of the spacing between the radioactive elements **86** (FIG. 2C). Thus, the ideal spacing of the elements **86** (of 0.4 inch for L in Equation 11) is of the order of 0.4 to 0.5 inch center-to-center in the constructed decharger **12**. This spacing is, of course, that established by the strontium-90 beta particle range from the elements **86** in the fluid (fuel). The actual center-to-center spacing between elements **86** is, of course, 0.4 inch and this is desirable for producing a stronger field with the element width (L) of 0.4 inch. A larger spacing between elements **86** would make the elements **86** appear more like rods instead of plates. The closer spacing produces an apparently more uniform spacing between the parallel plane, ground potential, elements **86** and a minimum activity (curies) for adequate ionization would be required to produce an ion density much greater than that responsible for the charge on the fluid. As mentioned earlier, the criticality of keeping the radiation down but getting a sufficient number of ions is reflected in the value of I, the number of ions produced per disintegration. It makes all the difference between practicality and impracticality in that the value of I was sufficiently large and this constituted a significant discovery.

While certain exemplary embodiments of this invention have been described above and shown in the accompanying drawings, it is to be understood that such embodiments are merely illustrative of, and not restrictive on, the broad invention and that I do not desire to be limited in my invention to the specific details of construction and arrangements shown and described, for obvious modifications may occur to persons skilled in the art.

I claim:

1. A process of reducing electrostatic charges in an electrically charged fluid, which comprises the steps of:

subjecting said charged fluid to ionizing radiation of predetermined intensity and ionization to render it conductive and elevated to at least a predetermined ion density for a predetermined time duration;

contacting said charged fluid to grounded structure during said predetermined time duration; and

draining said charges in said charged fluid to ground through said grounded structure while said charged fluid is rendered conductive.

2. The invention as defined in claim **1** wherein said radiation is of predetermined characteristic range, and said grounded structure is of predetermined dimensions and includes radioactive material of predetermined activity, and further comprising the step of flowing said charged fluid at a predetermined rate through said grounded radioactive structure of predetermined dimensions whereby said charged fluid is subjected to said ionizing radiation to render it conductive and elevated to at least said predetermined ion density while passing through and contacting said grounded radioactive structure.

3. Means for reducing electrostatic charges in an electrically charged fluid, said charge reducing means comprising:

means for subjecting said charged fluid to ionizing radiation of predetermined intensity and ionization to render it conductive and elevated to at least a predetermined ion density for a predetermined time duration; and

means for contacting said charged fluid to ground and draining said charges in said charged fluid to ground while it is rendered conductive, whereby said charged fluid is decharged to at least a predetermined level.

4. The invention as defined in claim **3** wherein said radiation includes beta radiation with its characteristic range, and said contacting and charge draining means includes a conductive means for housing said charged fluid, and ground means connecting with said conductive housing means.

5. A process of reducing electrostatic charges in an electrically charged fluid, which comprises the steps of:

subjecting said charged fluid to ionizing radiation to render a laminar layer thereof conductive;

draining said charges in said laminar layer to ground while it is rendered conductive and leaving charges in said laminar layer equally opposite to the charges in the remainder of said charged fluid; and

mixing said laminar layer with said remainder of said charged fluid to neutralize the same.

6. The invention as defined in claim **5** further comprising the step of flowing said charged fluid through a radioactive structure to subject it to ionizing radiation.

7. Means for reducing electrostatic charges in an electrically charged fluid, said charge reducing means comprising:

means for subjecting said charged fluid to ionizing radiation to render a laminar layer thereof conductive;

means for draining said charges in said laminar layer to ground while it is rendered conductive and leaving charges in said laminar layer equally opposite to the charges in the remainder of said charged fluid; and

means for mixing said laminar layer with said remainder of said charged fluid to neutralize the same.

8. The invention as defined in claim **7** wherein said fluid subjecting means includes a radioactive sleeve through which said charged fluid can be flowed and subjected to ionizing radiation to render a laminar layer thereof conductive.

9. The invention as defined in claim **8** further comprising a needle electrode, charge extracting means positioned upstream of said sleeve for reducing exceptionally high levels of electrostatic charges in said charged fluid prior to reaching said sleeve.

10. The invention as defined in claim **8** wherein said charge draining means includes a conductive means for mounting said sleeve therein and for housing said charged fluid, and ground means connecting with said conductive housing means, said sleeve being conductive and mounted in ground contact to said conductive housing means whereby said sleeve also serves as part of said charge draining means.

11. The invention as defined in claim **10** wherein said sleeve includes a radioactive material therein for providing a predetermined available activity and radiation range to produce said equally opposite charges in said laminar layer.

12. The invention as defined in claim **11** wherein said radiation range is correlated with flow of said charged fluid to provide a thickness of said laminar layer in which the inner velocity thereof is approximately equal to a predetermined percentage of the mean flow velocity of the central core portion of said charged fluid.

13. Means for reducing electrostatic charges in an electrically charged fluid, said charge reducing means comprising:

means for subjecting said charged fluid to ionizing radiation to render it conductive, said fluid subjecting means including a radioactive structure having a plurality of passageways through which said charged fluid can be flowed and subjected to ionizing radiation to render it conductive; and

means for draining said charges in said charged fluid to ground while it is rendered conductive.

14. The invention as defined in claim **13** wherein said structure comprises a radioactive grating through which said charged fluid can be flowed and subjected to ionizing radiation to render it conductive.

15. The invention as defined in claim **14** wherein said grating includes elements having a selected radioactive material therein for providing a predetermined available activity and radiation range, said elements having a predetermined configuration and being arranged in a predetermined geometry in said grating to ionize the volume of said charged fluid passing through it.

16. The invention as defined in claim **14** further comprising a needle electrode, charge extracting means positioned upstream of said grating for reducing exceptionally high levels of electrostatic charges in said charged fluid prior to reaching said grating.

17. The invention as defined in claim **14** wherein said charge draining means includes a conductive means for housing said charged fluid and ground means connecting with said conductive housing means, said grating being conductive and mounted in ground contact to said conductive housing means whereby said grating also serves as part of said charge draining means.

18. The invention as defined in claim **17** wherein said grating includes a plurality of radioactive strip elements each having a generally rectangular plate configuration of predetermined length, width and thickness, said elements being positioned in parallel with their planes aligned generally with fluid flow direction and having a uniform spacing between said elements correlated to the mean range of said ionizing radiation.

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