May 15, 1951 W. H. FARR ET AL 2,553,179

DETECTION OF TOXIC GASES, PARTICULARLY CARBON MONOXIDE

Filed Oct. 15, 1948 3 Sheets-Sheet 1

Fig. 1.

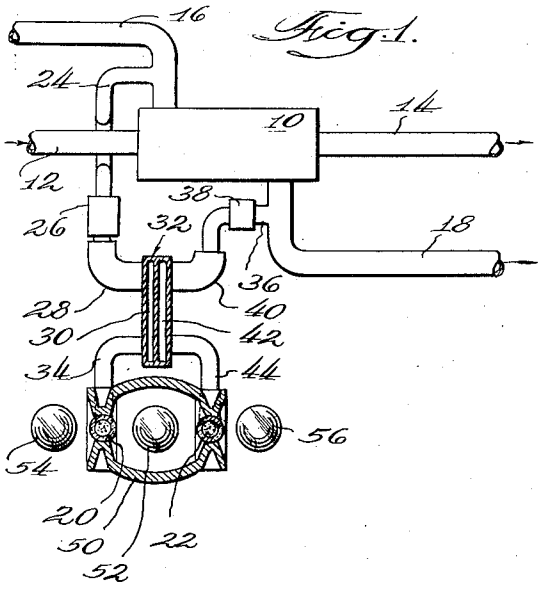


Fig. 2.

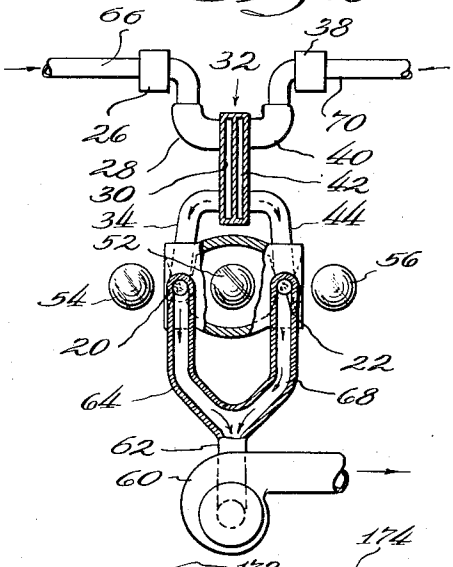


Fig. 7.

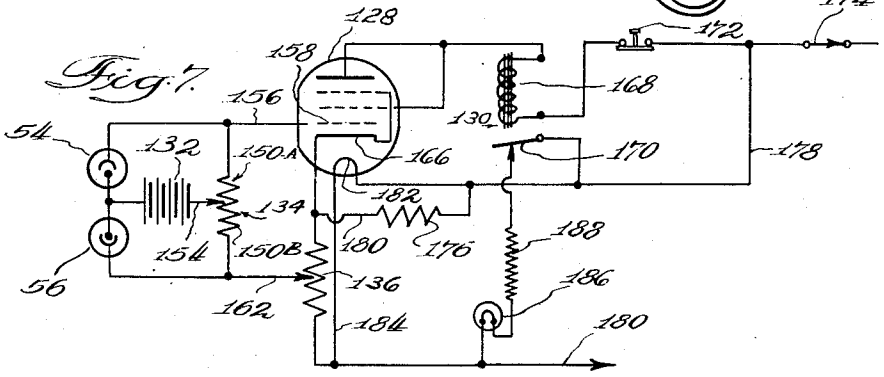
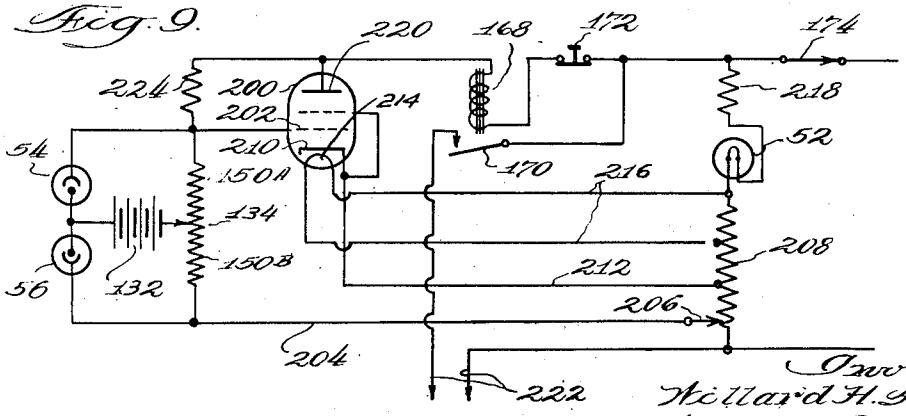


Fig. 9.



Inventors
Willard H. Farr
William F. Fagen
Stanley Kolanowski
By Williams, Bradbury & Hinkle
Attorneys

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DETECTION OF TOXIC GASES, PARTICULARLY CARBON MONOXIDE

Filed Oct. 15, 1948 3 Sheets-Sheet 2

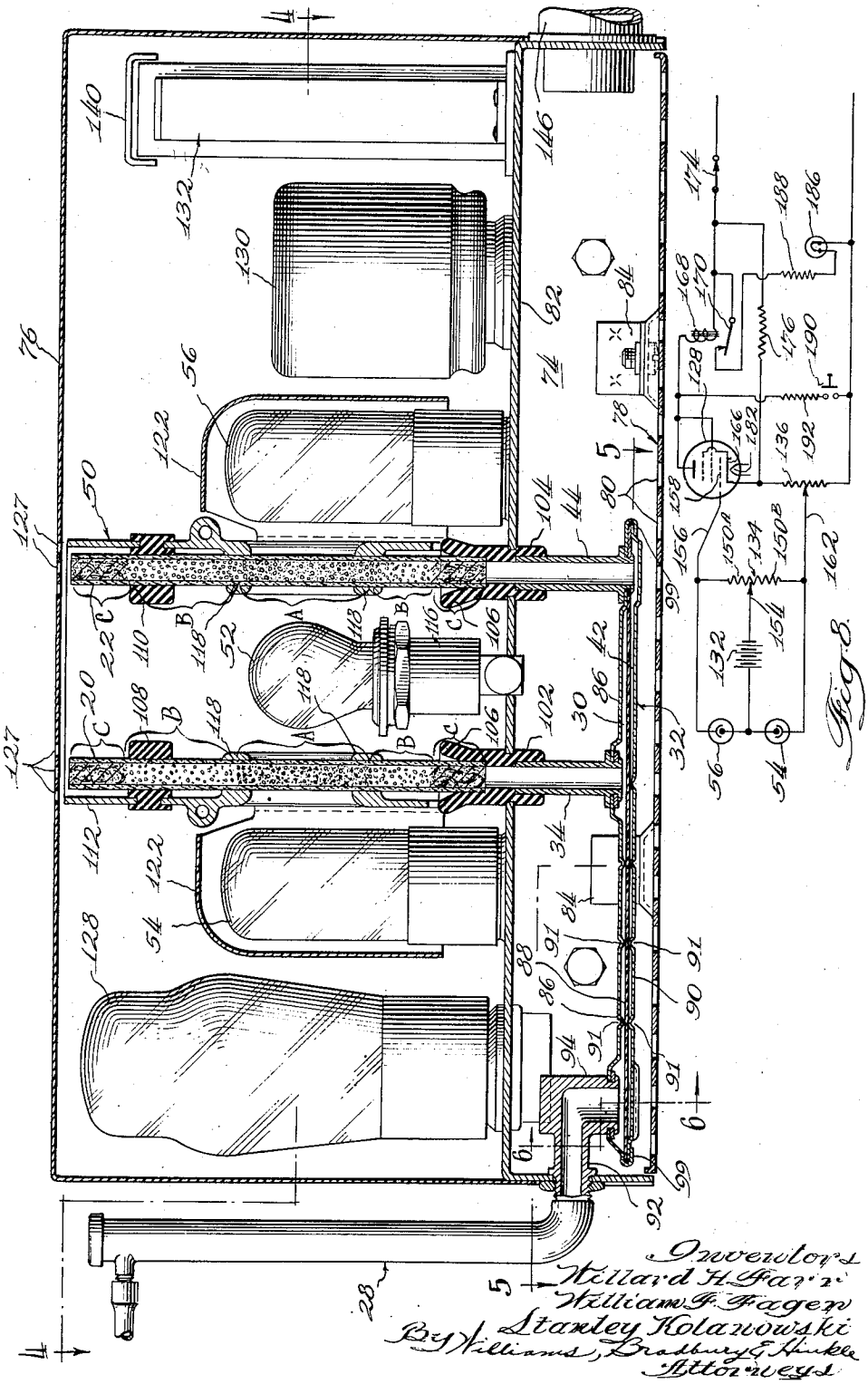


Fig. 3.

Fig. 8.

Inventors
Willard H. Farr
William F. Fagen
Stanley Kolanowski
By Williams, Bradbury & Hinkle
Attorneys

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DETECTION OF TOXIC GASES, PARTICULARLY CARBON MONOXIDE

Filed Oct. 15, 1948 3 Sheets-Sheet 3

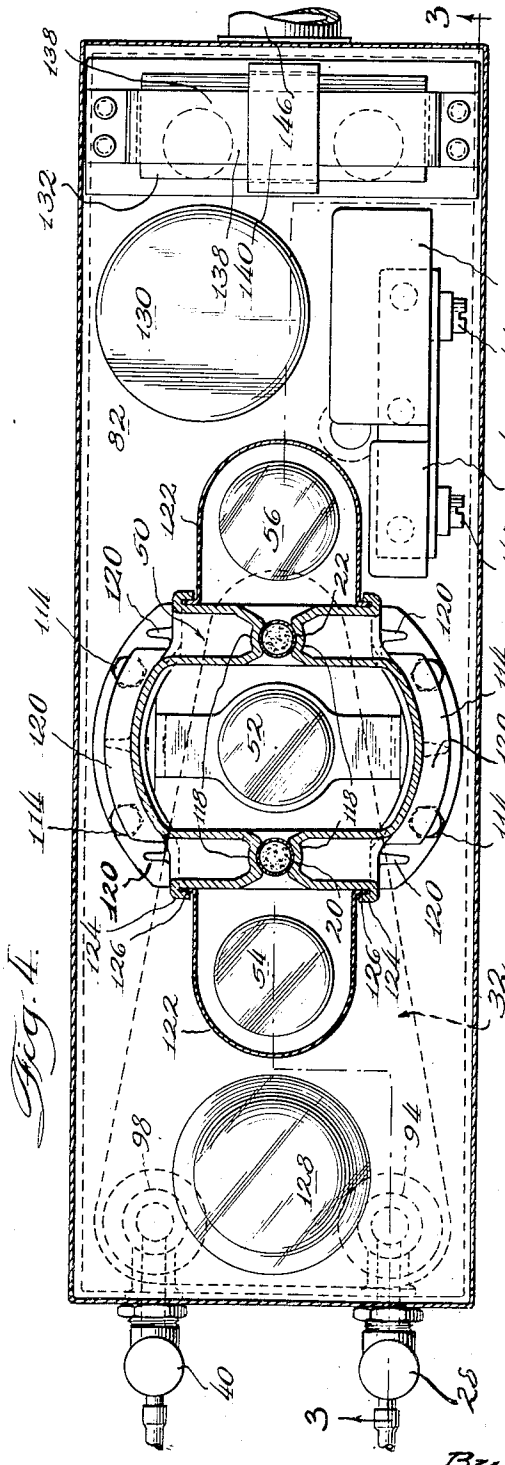


Fig. 4.

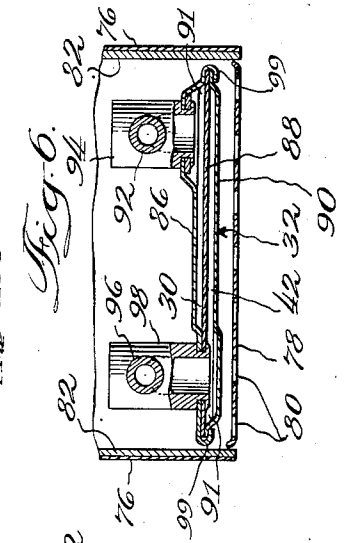


Fig. 6.

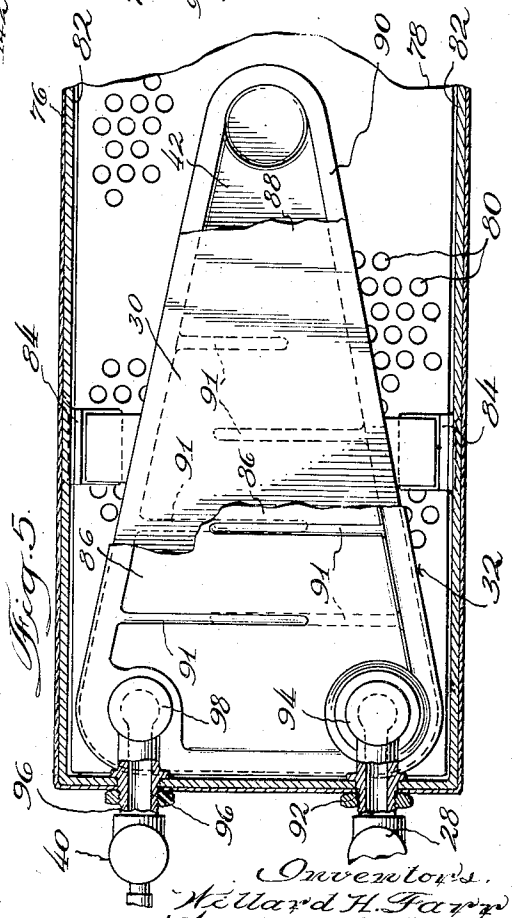


Fig. 5.

Inventors.
Willard H. Farr
William F. Fagen
Stanley Kolanowski
By Williamson, Bradbury & Hinkle Attorneys.

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UNITED STATES PATENT OFFICE

2,553,179

DETECTION OF TOXIC GASES, PARTICULARLY CARBON MONOXIDE

Willard H. Farr, Chicago, Ill., William F. Fagen, Gainesville, Fla., and Stanley C. Kolanowski, Chicago, Ill., assignors to Stewart-Warner Corporation, Chicago, Ill., a corporation of Virginia

Application October 15, 1948, Serial No. 54,802

2 Claims. (Cl. 23—255)

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The present invention relates to improvements in the detection of toxic gases, particularly carbon monoxide and is a continuation in part of our earlier application Serial No. 478,324, filed March 6, 1943, now abandoned.

The primary object of the present invention is to provide new and improved apparatus for detecting the presence of toxic gases, especially carbon monoxide.

A further object of the present invention is to provide apparatus of this character that may be easily constructed, and which is extremely sensitive.

A further object of the present invention is the provision of apparatus of the character described, which is particularly adapted for detecting the presence of carbon monoxide in the cabins of airplanes, especially airplanes heated by means of the airplane engine exhaust gases.

A further object of the present invention resides in the provision of new and improved apparatus for detecting carbon monoxide which includes a substance having a photocharacteristic—preferably the light transmission characteristic—that changes when it is subjected to the presence of carbon monoxide.

Another object of the present invention resides in the provision of new and improved apparatus for detecting carbon monoxide wherein the sensitive substance is placed in a pair of transparent tubes arranged equidistantly from a single light source and controlling the passage of light to a pair of photosensitive devices and wherein heated air is passed through one tube and unheated air through the other.

Another object of the invention is to provide an apparatus as set forth in the previous paragraph, wherein the photosensitive devices are arranged in electric circuits so that the apparatus will respond to slight changes in carbon monoxide content, and wherein any changes in the light transmitting characteristics, as by aging or the like, will not affect operation of the apparatus.

A further object of the present invention is to provide a new and improved apparatus including photosensitive devices and circuits which may be readily adjusted to provide balanced conditions for equal or different light intensities impinging upon the devices.

Another object of the present invention is to provide an improved apparatus of the character described, wherein the sensitivity of the apparatus to the presence of carbon monoxide may be readily adjusted.

A further object of our invention is to provide

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a carbon monoxide detector which will not respond to the presence of carbon monoxide if the carbon monoxide is in the fresh air to be heated, as might be the case when the airplanes are flying in formation and some of the exhaust gases from one plane enter the cabin of a following plane.

Another object of our invention is to provide a carbon monoxide detection apparatus wherein provision is made to eliminate any possible errors resulting from temperature differences between the heated and unheated air supplied to the tubes containing the sensitive substance.

Another object of our invention is to provide apparatus of the character specified so constructed and arranged as to give indication of the presence of carbon monoxide and also of the operative condition of the electrical circuits and photosensitive devices associated therewith.

A still further object of the invention resides in the physical construction of the apparatus, in the construction of a heat exchanger utilized to bring to an equal temperature the heated and unheated air supplied to the sensitive substance containing tubes, and in an apparatus wherein the tubes may be readily replaced.

Another object of the invention resides in the provision of a new and improved carbon monoxide detecting apparatus capable of being operated from a low voltage electric power source such as that commonly utilized in an airplane.

Other objects and advantages of the present invention will become apparent from the ensuing description, in the course of which reference is had to the accompanying drawings, in which:

Fig. 1 is a diagrammatic representation of an installation of the apparatus of our invention relative to an exhaust type airplane heater;

Fig. 2 is a view similar to Fig. 1 of an alternative installation requiring no connections to the airplane heating system and thus making it less vulnerable to gunfire;

Fig. 3 is a vertical cross sectional view illustrating the physical construction of the detection apparatus, the view being taken along the broken line 3—3 of Fig. 4;

Fig. 4 is a horizontal cross sectional view of the apparatus shown in Fig. 3, the view being taken along the line 4—4 of that figure;

Fig. 5 is a fragmentary horizontal cross sectional view of the apparatus taken along the broken line 5—5 of Fig. 3 and illustrating details of construction of a novel heat exchanger incorporated therein;

Fig. 6 is a fragmentary vertical cross sectional view of the apparatus illustrating further details

of the heat exchanger, the view being taken along the broken line 6—6 of Fig. 3;

Fig. 7 is a diagrammatic illustration of the electrical circuits embodied in the apparatus;

Fig. 8 is a view similar to Fig. 7 of another circuit arrangement possessing the advantage of providing an indication in the event certain circuits or devices are defective; and

Fig. 9 is another view like Figs. 7 and 8 illustrating a third circuit arrangement.

Before considering the details of the physical construction of and the electrical circuits embodied in the apparatus, it may be well briefly to consider their general character. In brief, apparatus of the present invention utilizes a pair of photosensitive devices preferably connected in a balanced differential bridge circuit and upon which impinges light from a single light source preferably located equidistantly between the devices. Between the light source and each of the two devices is located a transparent tube of material, such as glass, containing a substance, a photocharacteristic—preferably the light transmitting characteristic—of which changes in response to the presence of the substance to be detected, in this case carbon monoxide. Fresh air is passed through one of the tubes, which tube acts as a standard, while the air to be analyzed, in this case the heated air, is passed through the second tube. Inasmuch as the photosensitive devices are connected in a balanced bridge circuit, the unbalance of the circuit resulting from the change in color transmitting characteristics of the tube through which the heated air is passed is utilized to control an electronic tube. The electronic tube may be rendered either more or less conductive as a result of the unbalance to operate a relay or to return the relay to its non-operated position. The operation of the relay in either of these two ways may be used to perform some control operation, for instance the lighting of a warning signal lamp, the operation of a valve to cut off the further supply of heated air into the cabin, or the like.

The substance within the tube which is responsive to the presence of carbon monoxide is one known as the "National Bureau of Standards Colorimetric Carbon Monoxide Indicating Gel." The chemical description and method of making this gel are fully disclosed in an article under the title of "Rapid Determination of Small Amounts of Carbon Monoxide (Preliminary Report on the NBS Colorimetric Indicating Gel)" by Martin Shepherd. This article appeared in "Industrial and Engineering Chemistry" (Analytical Chemistry), volume 19, page 77, February 1947. This gel is yellow in color until exposed to carbon monoxide when its color changes from yellow progressively toward a dark blue-green.

Thus, in the event there is carbon monoxide present in the heated air supplied to the airplane cabin which may result from leakage from the heat exchanger, the substance in one of the glass tubes between the light source and one of the photosensitive devices changes progressively from yellow color to a dark blue-green color, thereby decreasing the amount of light impinging upon that photosensitive device. As a result, the bridge circuit becomes unbalanced, and this unbalance is utilized to operate a warning device, or the like.

In the further detailed description of the invention, attention will first be directed to Fig. 1 showing diagrammatically an installation upon an airplane having a heater of the exhaust type often used in airplanes. The exhaust gases are passed through a heat exchanger 10, which they enter through a conduit 12 and leave through a conduit 14. The air to be heated and to be supplied to the interior of the cabin flows to the heat exchanger through a cold air intake or duct 16. This air may be, and usually is, cold air taken from outside the cabin. The heated air is supplied to the interior of the cabin through an outlet conduit or hot air manifold 18.

Inasmuch as the primary purpose of the present invention is to provide an apparatus for detecting the leakage of carbon monoxide from the exhaust gases into the fresh air supplied to the interior of the cabin, it is desirable to compare the quantity of carbon monoxide in the inlet conduit 16 and the outlet conduit 18. The fresh air sample is continuously passed through a transparent glass tube 20, and the heated air similarly passed through a similar glass tube 22, both of which contain the carbon monoxide responsive substance referred to above.

The fresh air flows from the inlet conduit 16 to tube 20 through a conduit 24, a flow restrictor 26, a tube 28 containing silica gel, a heat exchanger chamber 30 forming part of a heat exchanger 32, and a conduit 34 connected to the lower end of tube 20. In a similar manner, heated air is supplied to tube 22 from the outlet conduit 18 through a conduit 36, a flow restrictor 38, a tube 40 also containing silica gel, a chamber 42 also forming part of heat exchanger 32, and a conduit 44 connected to the lower end of tube 22. The air in each case passes through the upper end of its associated tube, which is open to atmosphere—i. e., the interior of the cabin, or the wing of the airplane, or some other suitable place where the apparatus may be most conveniently located.

The flow of air through the tubes 20 and 22 is preferably continuous and is caused by the air pressures obtaining in the inlet and outlet conduits 16 and 18. It is preferred that the velocity be such as to maintain a positive flow of air without creating any undue physical disturbance. This flow is readily determinable by the flow restrictors 26 and 38, which may be in the nature of orifices or tube sections containing some restricting material such as glass or steel wool.

In order to prevent gasoline, alcohol or water vapors from affecting the operation of the apparatus, the tubes 28 and 40, filled with silica gel, are utilized to absorb these vapors. The vapors, thus, will not change the color of the substance within the tubes 20 and 22 to any marked degree. Even though the color of the substance be affected, the color change will usually be the same in both tubes because the unheated and heated air supplies are obtained from the same inlet conduit. The apparatus, also, will not be affected if the fresh air supplied to the interior of the cabin through the heat exchanger should contain some carbon monoxide, as might possibly be the case when one plane is flying very close behind another. Under these circumstances the change in the light transmitting characteristics in the same direction will have no effect thereon.

In order to avoid inaccurate readings because of temperature differences and in order to decrease the temperature of the heated air (which may be desirable in some instances, since excessive temperatures have a tendency to reduce the sensitivity of the sensitive substance), the samples are passed through the heat exchanger 32

for the purpose of bringing them to more or less the same temperature. The heat exchanger, it may be seen, is of the character where the two chambers 30 and 42 are in close contact with each other, whereby the air flowing therethrough is brought to much the same temperature. This heat exchanger is described in greater detail hereinafter.

The sensitive substance containing tubes 20 and 22 are mounted in a housing 50 to be described in greater detail hereinafter, centrally of which is also supported a single light source 52, which may be of any suitable construction and energized in any convenient manner.

The variations in the photocharacteristic, in this case the light transmitting characteristics, of the substance within the tubes 20 and 22 are measured by the photosensitive devices 54 and 56, between which and the light source the tubes are located. In order to provide the greatest sensitivity possible, these photosensitive devices are of the photoelectric type. Excellent results have been obtained with the type 923 photoelectric tubes.

Instead of utilizing the pressure of the air in the air inlet and outlet conduits to provide the requisite pressure for creating a flow of air through the tubes, this flow can be induced by means of a pump or aspirator or simply a connection to a region of low pressure. An alternate construction of this character utilizing a pump, illustrated in Fig. 2, enables the air samples to be taken directly from the outside of and interior of the cabin, respectively. This construction eliminates long connection conduits that might otherwise be necessary and makes the installation less vulnerable to gunfire.

Referring now to Fig. 2, it may be seen that fresh air is drawn through the tube 20 by a pump 60, the inlet end 62 of which is connected to the top of the tube by a conduit 64. The fresh air is supplied to the lower end of tube 20 from outside the cabin through a conduit 66, the flow restrictor 26, the silica gel tube 28, the heat exchanger chamber 30, and conduit 34. In like manner heated air from the interior of the cabin is drawn through tube 22 by the pump 60, the inlet conduit 62 of which is connected to the top of the tube through a conduit 68. The lower end of tube 22 communicates with the interior of the cabin through conduit 70, the flow restrictor 38, the silica gel tube 40, heat exchanger chamber 42 and conduit 44.

Attention will next be directed to the physical construction of the apparatus and particularly to the glass tube, lamp, electron tube, and photosensitive devices assembly, which is best illustrated in Figs. 3 to 6, inclusive.

Referring now more particularly to Figs. 3 and 4, it may be seen that the apparatus is housed in a portable structure comprising a chassis 74 and a removable cover 76. The chassis comprises a bottom plate 78, provided with a series of ventilating apertures 80, and an upper plate 82 upon which various elements are mounted. The bottom and upper plates of the chassis are suitably secured together as by brackets 84 to provide a space for the heat exchanger 32 and its connections.

The heat exchanger, which is of novel construction, has a generally triangular configuration as may best be noted from Fig. 5 and comprises an upper plate 86 and an intermediate plate 88 that are spaced apart to form the heretofore referred to heat exchanger chamber 30. The intermediate plate 88 and a bottom plate 90 are also spaced apart to form the second heat exchanger chamber 42. The top and bottom plates 86 and 90, respectively, are provided with spaced apart, inwardly extending channels or ribs 91 extending into contact with the intermediate plate 88 to provide baffles so that the air must follow a sinuous path through the heat exchanger. This construction provides a more uniform and equal temperature for both the heated and unheated air entering the glass tubes and lowers the temperature of the heated air.

The unheated, or fresh, air is supplied to the sensitive substance containing tube 20 through the silica gel containing tube 28, which is supported immediately outside the unit upon a nipple 92 extending within and secured to the chassis. The inner end of the nipple is provided with a head 94 secured to the upper plate 86 of the heat exchanger near one base corner, as best shown in Figs. 3 and 6. The heated air is supplied to the heat exchanger chamber 42 through the silica gel containing tube 40, a nipple 96 similar to nipple 92, the head 98 of which is secured to both the upper and intermediate plates near another base corner, as best illustrated in Fig. 6. The plates are all held together by the reversely bent-over peripheral edge 99 of plate 86.

The tubes 20 and 22 containing the carbon monoxide sensitive substance communicate with the heat exchanger chambers 30 and 42 through the conduits 34 and 44 and through rubber bushings 102 and 104, respectively. The bushings are secured to the top plate 82 of the chassis and fixedly receive the upper ends of the conduits 34 and 44, respectively. The upper ends of the rubber bushings 102 and 104 are flared, as indicated by reference characters 106, in order more readily and removably to receive the tubes. The lower end of conduit 34 is secured to the upper plate 86 of the heat exchanger so that it communicates with heat exchanger chamber 30 and the lower end of conduit 44 is secured to both the upper and intermediate plates 86 and 88 near their apices so that it communicates with chamber 42.

The glass tubes 20 and 22 are removably held in place by the bushings 102 and 104 and by rubber grommets 108 and 110 apertured closely to receive the tubes and secured to the top wall 112 of the lamp housing 50. The lamp housing 50 is constructed of two symmetrical parts, each of which is secured to the top plate of the chassis by bolts 114 (see Fig. 4). The light bulb 52 is mounted centrally of this housing in suitable manner, as in a socket 116 (see Fig. 3).

To reduce the quantity of carbon monoxide sensitive substance that must be placed in the tubes 20 and 22, the lamp housing is so constructed and arranged relative to tubes that light from the lamp passes through but a limited portion of the length of the tubes. Thus, the lamp housing parts are constructed with central oppositely extending parts 118 (see Fig. 4) that are spaced apart and configured to receive the tubes 20 and 22, respectively.

The tubes 20 and 22 thus need be filled with but a limited amount of the carbon monoxide sensitive substance, as shown in Fig. 3, where central portions of the tubes are filled by the substance as indicated by the reference characters A. To each side of the sensitive substance there is placed a quantity of silica gel, the extents of which are indicated by the reference characters B, and the ends of the tubes are filled with some inert material such as glass wool, as indi-

cated by the reference characters C, which does not materially impede the flow of air through the tubes.

In order to prevent the temperature within the lamp housing from rising too high, the housing is provided in its exterior with radiator fins 120.

The photoelectric tubes 54 and 56 are mounted on the chassis immediately adjacent the lamp housing in such manner that the photoelectric tubes, lamp and glass tubes are all in a straight line. The photoelectric cells are substantially fully enclosed by metal shields 122 detachably secured to the lamp housing as by a sliding connection constituted by flanges 124 and 126 on the housing and shields, respectively. The air passing upwardly through the tubes flows outside the cover 76 through suitable apertures 127 formed in the cover.

The chassis also supports an electron tube 128, a relay 130, a battery 132 and a pair of adjustable resistors 134 and 136, the functions of which will be described shortly. The relay 130 is of the plug-in type, and the battery is held in place by a pair of straps 138 and 140. The resistors are adjustable by means of adjusting screws 142 and 144. The electrical conductors, through which power is supplied, and/or through which the control functions are exercised may be led within the chassis through a sleeve 146.

The location of the battery 132 in the same enclosure with the light source and electron tube permits the utilization of the heat generated by them to heat the battery and keep it from being frozen, as might be the case when the airplane flies in extremely cold weather or at high altitude. If the heat generated by the lamp and tube is not sufficient, additional heat may be provided for preventing freezing of the battery. No heating would, of course, be required if the apparatus was located in the normally heated cabin of an airplane.

The photoelectric tubes are arranged in a balanced differential circuit, whereby the sensitive substance in one tube can be used as a standard, and any gradual drift in color of both tubes is balanced out. Referring now more particularly to Fig. 7, it may be seen that the photoelectric tubes 54 and 56 constitute two legs of a bridge, the other two legs of which are constituted by portions 150—A and 150—B of the resistor 134. Because of the low voltage supply (24 volts) usually found in airplanes, it is preferred, in order to provide a balanced circuit arrangement, to utilize a separate source of potential for the bridge circuit such as, for instance, a 45 volt battery 132, the positive terminal of which is connected to anodes of the photoelectric tubes and the negative terminal of which is connected to the resistor 134 through a connection 154 adjustable by adjustment of the screw 142, which connection is utilized for the purpose of balancing the bridge circuit. The junction between the photoelectric tube 54 and resistor portion 150—A is connected by the conductor 156 to the grid 158 of the electron tube 128 which may be of the high vacuum type (of the 25B6G type). The junction between resistor portion 150—B and photoelectric tube 56 is connected by a connection 162 adjustable by adjustment of the screw 144 to the bias resistor 136 in circuit with the cathode 166 of the electron tube. This connection is utilized to adjust the sensitivity of the apparatus—i. e., the change in light transmitting characteristics of the substance in tube 22 associated with the photoelectric tube 56 necessary to operate a relay or the like.

In adjusting the apparatus the adjustable connection 154 is first adjusted to balance the bridge circuit, after which the connector 162 is adjusted to bring the grid bias applied to grid 158 to a desired point below the value of plate current required to operate a relay 130 in the plate circuit of the tube. In the illustrated embodiment the relay includes a winding 168 and a normally closed contact 170. The winding 168 is connected to the positive terminal of the usual 24 volt supply found on the airplane through a normally closed relay resetting switch 172 and a main switch 174, which is closed when the apparatus is in operation.

One of the features of the present invention, as already indicated, resides in the effective utilization of the low voltage supply of the airplane. To provide a sufficient negative bias to the grid of the control tube independently of the flow of current through the tube, there is provided a bleeder resistor 176 connected to the positive power supply line through conductor 178 and to the cathode 166 by a conductor 180. The current through the bleeder resistor thus flows through the bias resistor 136 to the negative power supply conductor 180. The cathode heater 182 is connected across the power supply lines 174 and 180 by the conductor 178 and a conductor 184.

The relay switch 170 may be utilized to control a suitable indicating device or some device controlling the flow of heated air into the airplane cabin. In the indicated arrangement the switch controls the warning light 186, which is normally connected across the power supply lines through the switch 170 and a current limiting resistor 188.

Before proceeding with the description of the alternate forms of circuit, it is thought best to review the operation of the embodiment of the invention described above. If the installation illustrated in Fig. 1 is utilized, then fresh air obtained from the inlet conduit 16 is passed through the sensitive substance containing tube 20 and air obtained from the hot air duct 18 is passed through the sensitive substance-containing tube 22, through the passages heretofore described in detail. Or, if the arrangement of Fig. 2 is utilized, air from outdoors is passed through the tube 20, and air from within the cabin is passed through the tube 22. In either case, the air flows through the tubes at a relatively slow velocity and the two air samples are brought to approximately the same temperature by passing the air through the heat exchanger 32. Alcohol or gasoline vapors are removed from the air stream by the silica gel in the instrument entrance tubes 28 and 40, which are located just ahead of the heat exchanger.

The light source 52 is usually energized continuously although, if desired, it can be energized simultaneously with the remainder of the apparatus through the power switch 174. Light from the lamp passes through the portions of tubes 20 and 22 containing the substance sensitive to carbon monoxide and impinges upon the photoelectric cells 54 and 56.

It is possible to insert new tubes 20 and 22 at desired intervals or just before each flight of the airplane, in order to make certain that the tubes have not been previously discolored. If they have not been discolored, then they both possess the same light transmitting character-

istics with the result that the photoelectric tubes have the same amount of light impinging thereon. However, if the light transmitting characteristics are not exactly the same, the bridge circuit may be balanced by adjustment of the connection 154. When so balanced any gradual drift or change in color of the carbon monoxide sensitive substance will not affect the flow of current through the relay winding 168, since the currents flowing through the resistor portions 150—A and 150—B are equal and opposite. Consequently, the potential applied to grid 158 is unaffected by the drift or change in color.

The sensitivity of the apparatus is readily adjustable by movement of connection 162 to vary the effective portion of the voltage drop across bias resistor 136 applied to the grid 158. The grid is biased to a desired point—usually a point just below that at which the flow of current through the relay winding 168 is insufficient to operate the relay. This grid potential is such that current normally flows through the relay winding and also through the tube and the bias resistor. This current flow is, however, insufficient to provide the necessary bias for the grid, but the flow of current through the bias resistor is increased and made more constant by use of the bleeder resistor 176.

When there is no carbon monoxide present in the heated air, the light 186 is connected across the power supply lines by the relay switch 170 and glows continuously. However, when there is carbon monoxide present in the heated air, as might be the case when the heat exchanger is punctured by a bullet, then the carbon monoxide changes the light transmitting characteristics of the sensitive material in the tube 22. As a result less light passes through the tube and the photoelectric tube 56 produces a smaller electron flow. The net result is that the current flow through the local circuit connected across battery 132 and including the tube 56 and resistor portion 150—B is reduced. This reduction in current flow through resistor portion 150—B results in the application of an increased positive potential on the grid 158, with the further result that the tube 128 becomes more conductive. As the current flow through the tube 128 increases to a point determined by the sensitivity adjustment, the relay winding 168 becomes energized sufficiently to open the switch 170 whereupon the lamp 186 is disconnected from its power supply to give an indication of the presence of carbon monoxide.

An apparatus constructed in accordance with this invention has proved to be very sensitive and, indeed, is capable of detecting the presence of small quantities of carbon monoxide in a relatively short period.

After operation of the relay, the apparatus may be reset for further detection and indication of the presence of carbon monoxide upon balancing the bridge circuit, which is accomplished by adjustment of the connection 154, and the momentary opening of switch 172. The switch 172 is provided so that the relay may be reset without cutting down the current flow through the tube by adjustment of the grid bias to a value below the release current of the relay, which is usually much less than the operating current. If the switch were not provided, it would be necessary to adjust the bias resistor 136 to some point whereat the current flow through the tube would be cut down to an extent sufficient to release the relay.

The balanced bridge circuit arrangement may be arranged to maintain the relay in its operated position when the amount of carbon monoxide does not exceed some predetermined value and to release the relay when the amount of carbon monoxide exceeds the aforesaid value. An advantage of this type of circuit arrangement is that it indicates also whether or not the circuit is operative, since, if the circuit should be inoperative, the relay is released to give an indication. An arrangement of this character is illustrated in Fig. 8, to which reference is now had.

The circuit of Fig. 8 corresponds quite closely to that illustrated in Fig. 7 with exception of the adjustment of the sensitivity control 162 relative to the bias resistor 136 and in the transposition of the photoelectric tubes 54 and 56. The aforesaid adjustment is so made that the normal grid potential maintains the relay operated switch 170 in its operated position, whereby the signal lamp 186 is normally lighted—in other words, the grid is normally more positive than in the first described embodiment and is rendered more negative when the presence of carbon monoxide is detected. The photoelectric tube 56 is placed in series with resistor portion 150—A so that when less light is transmitted to the tube as carbon monoxide changes the color of the sensitive gel in tube 22, less current flows through the resistor portion 150—A and the grid 158, which is connected to the junction of the cell and resistor portion, is rendered more negative. Thus, when the unbalance reaches a point determined by the setting of the grid bias adjustable connection 162, the flow of current through the relay winding 168 is decreased to a point where the switch 170 is released and the lamp 186 de-energized to give an indication of the presence of carbon monoxide.

In order to reset the relay without the necessity of increasing the flow of current through the electron tube 128 to a high value, there is provided a normally open switch 190 which, when closed, connects the relay winding across the power supply lines through a current limiting resistor 192; thus, momentary closure of the switch 190 after the bridge has been rebalanced resets the apparatus for a further detection operation.

The balanced bridge circuit arrangement may also be used in connection with gas tubes, as illustrated in Fig. 9, wherein a gas tube 200 of the 2051 type is used. The bridge circuit of this arrangement is identical with that illustrated and described in the embodiment of Fig. 7, i. e., the photoelectric cell 54 is connected in series with resistor portion 150—A, while the photoelectric cell 56 is connected in series with resistor portion 150—B. The junction of resistor 150—A and cell 54 is also connected to the grid 202 of the gas tube and the junction of resistor portion 150—B and cell 56 is connected by conductor 204 to an adjustable contact 206 associated with a bias resistor 208. The cathode 210 of the tube is connected by a conductor 212 to the resistor and the cathode heater 214 is also connected across a portion of the resistor by the conductors 216. The lamp 52 associated with the photoelectric cells is connected between the upper terminal and the bias resistor 208 and the positive power supply line through a resistor 218.

The relay winding 168 is in circuit with the anode 220 of the tube and the relay switch 170 controls a circuit 222 leading to a signal light or to some device for controlling the operation of the heater or the supply of heated air into the cabin.

In order to neutralize stray electron grid current and to provide a more perfect balancing of the bridge circuit, there is provided a neutralizing circuit between the anode and the grid including a high resistance resistor 224. This resistor is desirable in some cases and not necessary in others, dependent upon the characteristics of particular tubes.

The bridge circuit of the embodiment of Fig. 9 is balanced and the sensitivity adjusted in the same manner as these adjustments are made in the previously described embodiments. When the bridge circuit becomes unbalanced because of less light being transmitted to photoelectric cell 54, the grid 202 of the gas tube is rendered more positive with the result the relay winding 168 is energized more strongly until, at a point determined by the sensitivity adjustment 206, the relay operates to close switch 170 to indicate the presence of carbon monoxide or to shut off the supply of heated air or the like. If desired, the apparatus may be utilized to perform both functions, that is, both to give the signal and to operate some control apparatus to shut off the supply of heated air into the interior of the cabin.

From the foregoing detailed description of the details of apparatus embodying the invention, it may be noted that the apparatus may take various forms. It should be understood, therefore, the details of the various embodiments are not intended to be limitative of the invention except in so far as set forth in the accompanying claims.

Having thus described our invention what we claim as new and desire to secure by Letters Patent of the United States is:

1. Apparatus for detecting the presence of a contaminating substance in a gas which comprises means forming a case, a light source disposed within said case, a housing enclosing said light source, said housing having a pair of openings therein substantially equally spaced from said source, a pair of photosensitive devices disposed beyond said openings and adapted to receive light from said light source each through one of said openings, shielding means to exclude light from said photosensitive devices other than light passing through said openings, a pair of glass tubes larger in diameter than said openings, means forming guides to facilitate positioning of said glass tubes before said openings so that all of the light passing through one of said openings passes through one of said tubes while light passing through the other of said openings passes through the other of said tubes, sockets disposed beyond said guide means and adapted to embrace one end each of said tubes in airtight engagement so that said tubes can be inserted in said guide means with one end engaged in said sockets, each of said tubes containing a substance which undergoes a photocharacteristic change in the presence of the contaminant to be detected, a pair of inlet fittings disposed on said case, one of said fittings being adapted for connection to a source of gas known not to be contaminated and the other of said fittings being adapted for connection to a source of gas to be tested for the contaminant, conduit means connecting one of said fittings to one of said sockets and the other of said fittings to the other of said sockets, said conduits comprising together a heat exchanger to exchange heat from one of said conduits to the other of said conduits so as to equalize the temperature of gases flowing through said conduits, circuit means including amplifying means for balancing the outputs of said photoelectric devices against each other and relay means operable upon a predetermined amount of unbalance in said outputs, said relay being adapted for actuating an alarm when so operated, and circuit means for energizing said light source.

2. Apparatus for detecting the presence of a contaminating substance in a gas which comprises means providing a light source, a housing enclosing said light source, said housing having a pair of openings therein, a pair of photosensitive devices disposed beyond said openings and adapted to receive light from said light source each through one of said openings, a pair of glass cells sufficiently large to cover said openings, means forming guides to facilitate removable positioning of said glass cells before said openings so that all of the light passing through one of said openings passes through one of said cells while light passing through the other of said openings passes through the other of said cells, sockets adapted to connect to one end of each of said cells in airtight engagement so that said cells can be easily inserted in said guide means with one end engaged in said sockets, each of said cells containing a substance which undergoes a photocharacteristic change in the presence of the contaminant to be detected, a pair of inlet fittings, one of said fittings being adapted for connection to a source of gas known not to be contaminated and the other of said fittings beind adapted for connection to a source of gas to be tested for the contaminant, conduit means connecting one of said fittings to one of said sockets and the other of said fittings to the other of said sockets, circuit means for energizing said light source and for balancing the outputs of said photoelectric devices against each other and including means operable upon a predetermined amount of unbalance in said outputs, the last said means being adapted for actuating an alarm when so operated, whereby gradual change in the photocharacteristic of said substance due to aging will not operate the last said means but relative change due to contamination of one of said gas sources will operate the last said means.

WILLARD H. FARR.
WILLIAM F. FAGEN.
STANLEY C. KOLANOWSKI.

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