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TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 573

CARBON-MONOXIDE INDICATORS FOR AIRCRAFT

By S. H. J. Womack and J. B. Peterson
National Bureau of Standards

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By S. H. J. Womack and J. B. Peterson

SUMMARY

Several improvements that have been made on commercially available carbon-monoxide indicators to make them more suitable for aircraft use are described. These improvements include an automatic flow regulator, which permits the use of a simplified instrument on aircraft where a source of suction is available, and a more reliable alarm attachment. A field method for testing instruments on standard samples of carbon monoxide is described. Performance data and instructions in operation and maintenance are given.

INTRODUCTION

According to reference 1, the maximum concentration of carbon monoxide at normal atmospheric pressure to which a person may be exposed without harm for one hour is 0.04 percent by volume. In a more recent report (reference 2) Diringshofer and Hartmann conclude that the permissible concentration by volume is 0.02 percent at zero altitude and falls to 0.005 percent at about 15,000 feet. Carbon monoxide in quantities dangerous to personnel may be present in the cockpit of an airplane or in the engine nacelle of an airship. This presence of carbon monoxide may occur by a leak in an exhaust line when the exhaust from the engine is used to heat a cabin or compartment or may be caused by the flow of exhaust gases into the cockpit of an airplane by an unforseen condition of air flow. It is therefore advisable to have a carbon-monoxide indicator suitable for use in aircraft. In some cases a permanent installation is desired; in others merely a test to insure that the air flow about the aircraft is not such as to carry the engine exhaust into the cockpit or cabin.

The carbon-monoxide indicator, modifications of which are here discussed, was made by the Mine Safety Ap-

pliance Co. (MSA). The story of the development of this type of carbon-monoxide indicator is given in reference 1; further details are given in references 3 and 4. Other types of instruments are discussed in references 5, 6, 7, and 8. The instrument consists essentially of

a) a means for continuous sampling of the air to be tested,

b) a chemical for absorbing moisture,

c) a cell in which the carbon monoxide is converted to carbon dioxide, and

d) an indicator of the rise in temperature of the cell, which is graduated in terms of percentage of carbon monoxide.

White (reference 9) gives the results of tests on U. S. Navy airplanes using indicators of this type.

At the request and with the cooperation of the Bureau of Aeronautics of the Navy Department, certain of the commercially supplied instruments have been modified to make them more suitable for use on aircraft. These modifications have included

a) the addition of a regulating valve for automatically controlling the rate of flow of the air being sampled,

b) the use of a source of suction external to the instrument, and

c) remounting the parts so as to reduce the weight and size.

An alarm was perfected and added to an instrument intended primarily for airship use. Methods of test have been developed and performance data have been accumulated.

The cooperation of Dr. F. A. Smith, Chemistry Division, National Bureau of Standards, in developing a field test method is acknowledged. The cooperation of Mr. C. E. Earle and Mr. E. W. Rounds of the Bureau of Aeronautics was of great value during the course of the work. Funds for the preparation of this paper have been made available by the National Advisory Committee for Aeronautics.

DESCRIPTION OF MODIFICATIONS

In the instrument as usually furnished a motor and a vacuum pump are provided to draw the sample of air through the instrument. The schematic diagram of the air flow of this type of instrument is shown in figure 1. This arrangement is not ideal for aircraft in all cases since a source of current is needed for the motor and, more important, the bulk of the instrument adds to the inconvenience of installation. In the improved arrangment the source of suction is external to the instrument. The source may conveniently be the intake manifold of the gasoline engine or a small venturi tube mounted in the slipstream. A schematic diagram of the air flow in the carbon-monoxide indicator so modified is shown in figure 2.

Air that is being tested flows continuously through the instrument (figs. 1 and 2), through a canister containing a chemical drying agent, a capillary tube type flow indicator, a hopcalite cell and, in the case of the modified instrument, the flow regulator.

From this point on the description will be confined to the modified instrument. Photographs are shown in figures 3, 4, and 5.

The heart of the instrument is the hopcalite cell (references 1 and 10), in which the carbon monoxide is converted to carbon dioxide. This cell is shown in detail in figure 6. Hopcalite is the trade name for a granular mixture of manganese dioxide and copper oxide, which serves as a catalyst for the reaction. One end of the hopcalite cell A (fig. 6) is filled with active and the other B (fig. 6), with inactive chemical. A series of thermocouples T (fig. 6) is used to measure the difference in temperature between the inactive and active parts of the cell. The output of the thermocouples is indicated by a voltmeter J (figs. 3 and 4), which is graduated to indicate carbon-monoxide content in the range from 0 to 0.15 percent. The millivoltmeter supplied with the instrument has a range of approximately 20 millivolts for full-scale deflection and a resistance of 65 ohms.

In view of the variation that may be experienced in the external sources of suction, such as a venturi tube, it was thought essential to provide an automatic flow regulator. The flow regulator is actually a suction reg-

ulator that maintains a constant suction inside of the metal bellows E (fig. 2). It follows that if this suction is constant the volume flow will also be constant. The rate of flow is adjustable over a wide range by means of the vertical valve stem at the center of the bellows and over a lesser range by means of the manual adjustment H (figs. 2 to 5). Although the instrument does not normally need hand adjustment, the manual-adjustment screw is accessible from the front of the instrument. (See H, figs. 3 and 5.) The manual adjustment consists essentially of a flat spring, the pressure of which on the top of the bellows is adjustable by means of the screw H (fig. 2). A view of the flow regulator is shown at E (fig. 5). The performance characteristics of the flow regulator are shown in figure 13.

The flow indicator is of the well-known capillary-tube type. A diaphragm-type manometer was substituted for the U-tube manometer used in the commercial instrument.

The shut-off valve G (figs. 2 and 3) is provided in order to prevent flow through the instrument when it is not in use.

The modified instrument is mounted in an aluminum case, the dimensions of which are 5-1/2 by 5-1/2 by 8-1/2 inches. It weighs 8.0 pounds.

DESCRIPTION OF ALARM ATTACHMENT

At the request of the Bureau of Aeronautics an alarm to indicate the presence of carbon monoxide in excess of 0.02 percent was added to an MSA instrument in 1933. The instrument was designed and constructed for continuous operation on the U. S. airship "Akron." At the time this alarm attachment was made, the suction-operated instrument previously described had not been developed; therefore, an instrument with a motor-operated pump was used. An external source of suction will probably be used on future alarm instruments.

A front view of the instrument with the alarm attachment is shown in figure 7 and an interior view, in figure 8. The parts of the instrument have been somewhat rearranged and housed in a new case.

A wiring diagram of the alarm is shown in figure 9. The telephone switch marked "test", "alarm", and indicator" on the panel (figs. 7 and 9) normally stands in the "alarm" position unless manually held in one of the other positions. When in the "alarm" position, the output of the thermocouples in the hopcalite cell goes directly to a Weston Model 534 relay. The relay controls the grid circuit of a type 171-A vacuum tube. A Burgess vacuum contact relay in the plate circuit of the vacuum tube controls the danger signal light ("danger", in fig. 7) and the buzzer alarm.

The percentage of carbon monoxide in the sample is indicated on the electrical instrument when the switch is held in the "indicator" position. If the instrument has been in continuous operation on the "alarm" position the indicator may be read immediately after the switch is moved to the "indication" position.

In order to test the operation of the relays and alarm apparatus, a means of applying a voltage to the first relay equivalent to that produced by air containing 0.02 percent carbon monoxide is provided. The telephone switch is held in the "test" position and the "test voltage adjustment" knob slowly turned up until the pointer of the electrical indicator reaches the 0.02 percent mark whereupon, after about 4 seconds, the alarm signals should operate. The purpose of the 4-second lag, which is produced by suitable design of the electrical circuit, will be explained in the next paragraph. Failure to operate in this test indicates need for adjustment of the electrical circuit as, for example, adjustment of the contacts of the relay. The frequency of test must be determined by experience.

The lag mentioned in the preceding paragraph is produced by a condenser installed across the contacts of the sensitive relay in the grid circuit of the vacuum tube. The contacts of the relay are normally closed and, with the condenser in the circuit, remain open for about 3 or 4 seconds before the alarm signals operate. Hence a continuous voltage must be maintained on the relay before it will operate. This arrangement prevents false alarms due to a momentary opening of the contacts caused by excessive vibration of the instrument. The condenser also reduces the amount of sparking at the contacts of the sensitive relay.

The buzzer alarm or horn is external to the instru-

ment and is connected to the electrical circuit at the binding posts on the panel marked "buzzer" as shown in figure 7.

The power requirement of the apparatus is 0.25 ampere, 110 volts direct curent. As shown in the electrical diagram, the vacuum-tube filament and the vacuum-pump motor are in series. The characteristics of the circuit are such that the vacuum-tube filament is not injured by the normal starting current of the motor.

PERFORMANCE CHARACTERISTICS

Tests of the carbon-monoxide indicators show the following:

1. The e.m.f. developed in the hopcalite cell is directly proportional to the carbon-monoxide content of the sample, within the limit of accuracy of the method of analysis of the carbon monoxide-air mixture (iodine-pentoxide method, limit ±0.003 percent).

2. For a mixture containing 0.05 percent carbon monoxide, the maximum indication occurred when the pressure gage of the flow indicator indicated approximately 1 inch of water. The indication of carbon monoxide is plotted against indication of flow in figure 10, where it is seen that the carbon-monoxide indication decreases 2 percent at differential pressures of 0.75 and 1.35 inches of water.

The rate of flow of gas through the hopcalite cell has been selected so that the instrument is normally operated on the flat top of the curve shown in figure 10. At this point the indication of carbon monoxide is practically independent of the rate of flow over a certain range.

Assuming that the flow indication is held constant by manual adjustment, the carbon-monoxide indication decreases as the air pressure decreases. Laboratory tests in an altitude chamber have checked this characteristic at altitudes to 13,000 feet. However, if the instrument is constructed to operate at sea level at a greater rate of flow than that corresponding to the top of the curve (fig. 10), the carbon-monoxide indication will not be ap-

preciably affected by a large decrease in rate of flow and will thus be practically independent of altitude.

3. The indication of the instrument against time, after a sample of given carbon-monoxide content is started through the system, is shown in figure 11. It is shown that five minutes is a safe interval to wait before taking a reading.

4. No appreciable change in indication is obtained for changes in instrument temperature in the range from -5° to 40°C. The tests were made using an instrument with a fresh hopcalite cell. Excessive change in reading with temperature is an indication of the necessity of renewing the hopcalite cell.

5. The performance of the automatic flow regulator is shown in figure 12. Within a wide range of suction the flow is held constant. A minimum suction across the indicator of about 4 inches of mercury is required for automatic operation. Operation on a suction as low as 1.5 inches of mercury (fig. 12) may be obtained by discarding the automatic feature and securing constant flow by hand regulation of the manual regulating screw.

OPERATION

There are a few general instructions applicable to the operation of any carbon-monoxide indicator or alarm of the hopcalite type. In order to protect the sensitive millivoltmeter, the indicator should be mounted for operation on aircraft on a shock cord or other vibration-absorbing mount. A flexible metallic, rather than a rubber, sampling tube should be used because rubber may contaminate the sample.

Before the instrument is started, the zero setting of the millivoltmeter, on open circuit, should be checked and adjusted if necessary. The flow of air through the instrument is controlled by the manual flow adjustment H (figs. 2 and 3) or by the needle valve E (fig. 1) until the differential pressure across the capillary-tube flow indicator is 1 inch of water, as indicated by the pressure gage C (figs. 1, 2, and 3). The instrument should be operated on fresh air until the temperatures in the hopcalite cell have become equalized as indicated by a

zero indication on the millivoltmeter. If the indication is not zero after an operating period of 10 minutes, it is recommended that the millivoltmeter pointer be reset to zero, after which the sample to be tested is started through the instrument. For correct indication the sample should flow for a period of at least 5 minutes.

METHOD OF FIELD TESTING

It is essential under some circumstances to be able to test carbon-monoxide indicators in the field. The method developed for this purpose has also proved to be convenient and adequate for calibration tests in the laboratory. The arrangement of the apparatus is shown in figure 13. The standard sample is a cylinder of air at high pressure (2,000 pounds per square inch) containing a small accurately known percentage of carbon monoxide. If 1 cylinder only is available, it should contain about 0.03 percent of carbon monoxide. Since the results of many tests indicate that the e.m.f. developed in the hopcalite cell is directly proportional to the carbon-monoxide content of the sample, it is thought that field tests at more than one point are unnecessary. A pressure gage for measuring the tank pressure and a reducing valve are mounted on a panel. A U-tube mercury safety valve, which serves primarily to protect the carbon-monoxide indicator from excessive pressure, is also used to indicate the input pressure.

An instrument to be tested is connected as shown in figure 13. A suction source must be provided if a suction-operated instrument is to be tested. The instrument is operated exactly as explained in the operating instructions previously given, except that the sample is drawn from the cylinder of known carbon-monoxide content. The fresh air for the preliminary operation of the instrument is drawn in at the pinch clamp T (fig. 10). If the reducing valve reduces the pressure to a fairly low and constant value, it is easy to manipulate the auxiliary needle valve and the pinch clamp at the same time so that the flow is transferred from fresh air to the sample of known carbon-monoxide content without subjecting any part of the instrument to excessive pressure or suction.

The time during which the carbon monoxide sample is allowed to flow through the instrument should not be

longer than necessary because of depletion of the sample and of the active hopcalite.

MAINTENANCE

The instrument requires servicing after approximately 20 hours of use. Ordinarily the drying canister should be replaced at this interval. Also the capillary tube of the flow indicator should be cleaned. A pipe cleaner has been found useful for this purpose.

The instrument should be tested for error in indication after this servicing, in order to determine the condition of the hopcalite. The hopcalite is believed to have a life of about 200 hours. The test is conducted as described under field tests, except that the preliminary operation on fresh air should be for a period of 1/2 hour. If the indication is not less than 90 percent of the correct value and has not decreased more than 10 percent since the previous overhaul, the hopcalite is still usable. It is recommended that this test be conducted at an instrument temperature as low as or lower than that which will be experienced in use. It has been found that tests at an instrument temperature of 20° C. are not entirely trustworthy in predicting the performance of the instrument at lower temperatures.

After the hopcalite has been renewed, the preliminary operation on fresh air before the first test should be for a period of about 2 hours; otherwise the test is the same as described under field tests.

National Bureau of Standards,
Washington, D. C., June 15, 1936.

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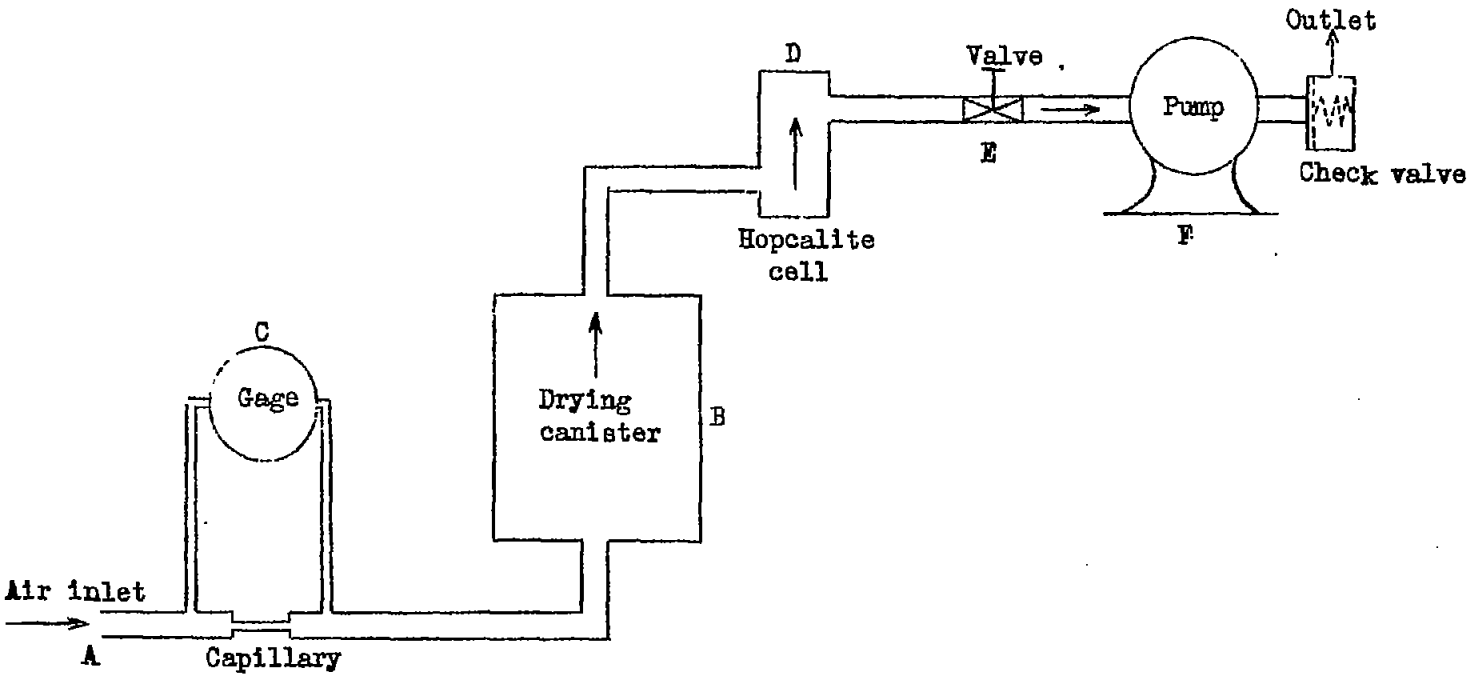

Figure 1.-Diagram of air flow in the usual form of carbon-monoxide indicator.

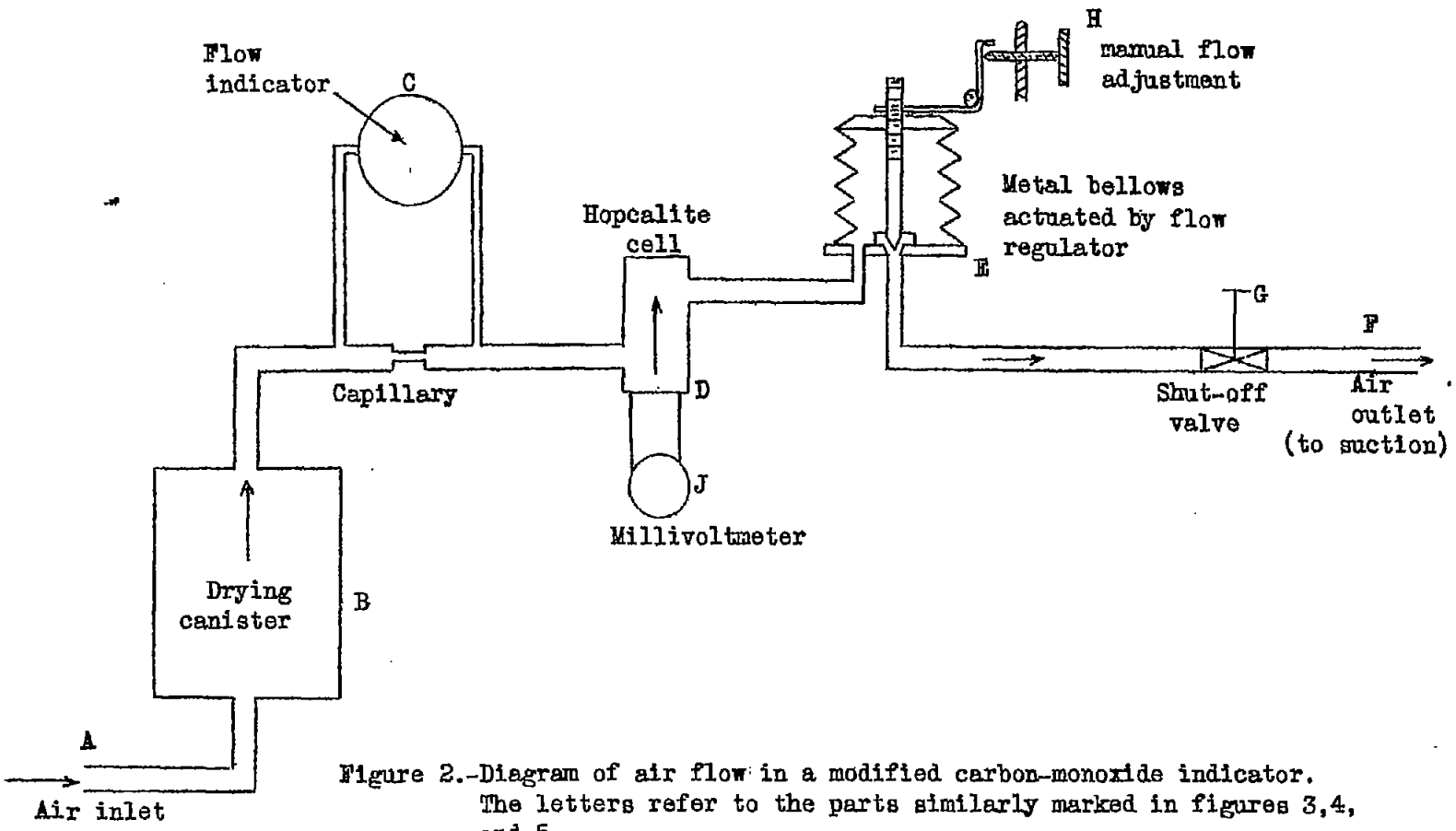

Figure 2.-Diagram of air flow in a modified carbon-monoxide indicator. The letters refer to the parts similarly marked in figures 3,4, and 5.

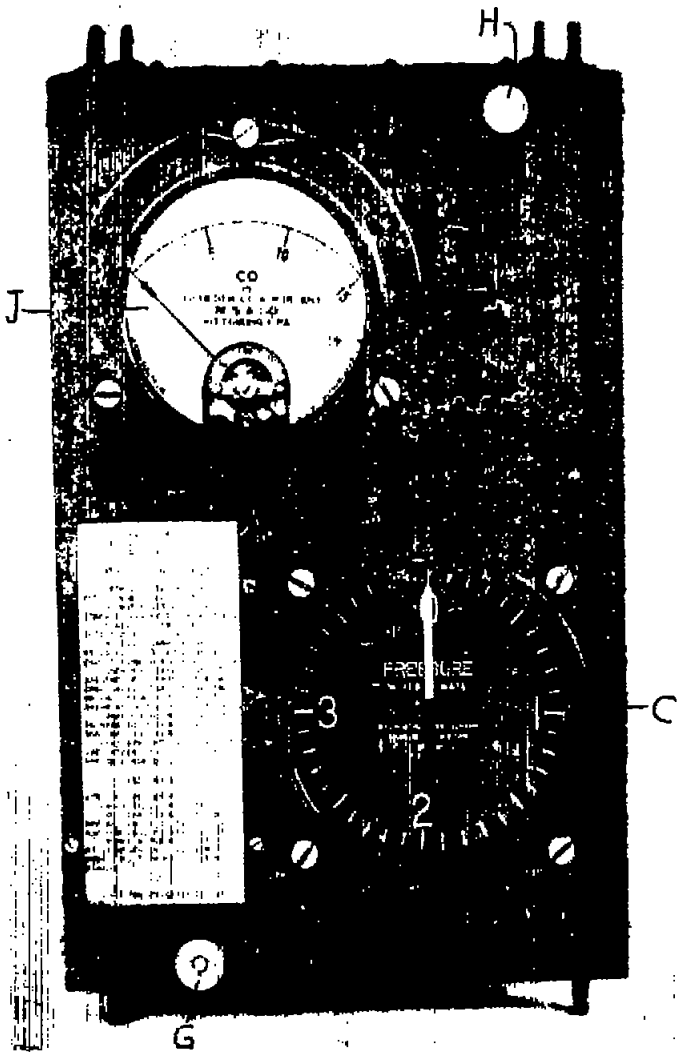

Figure 3.- Front view of modified carbon-monoxide indicator; C, flow indicator; G, shut-off valve; H, manual flow adjustment; and J, millivoltmeter.

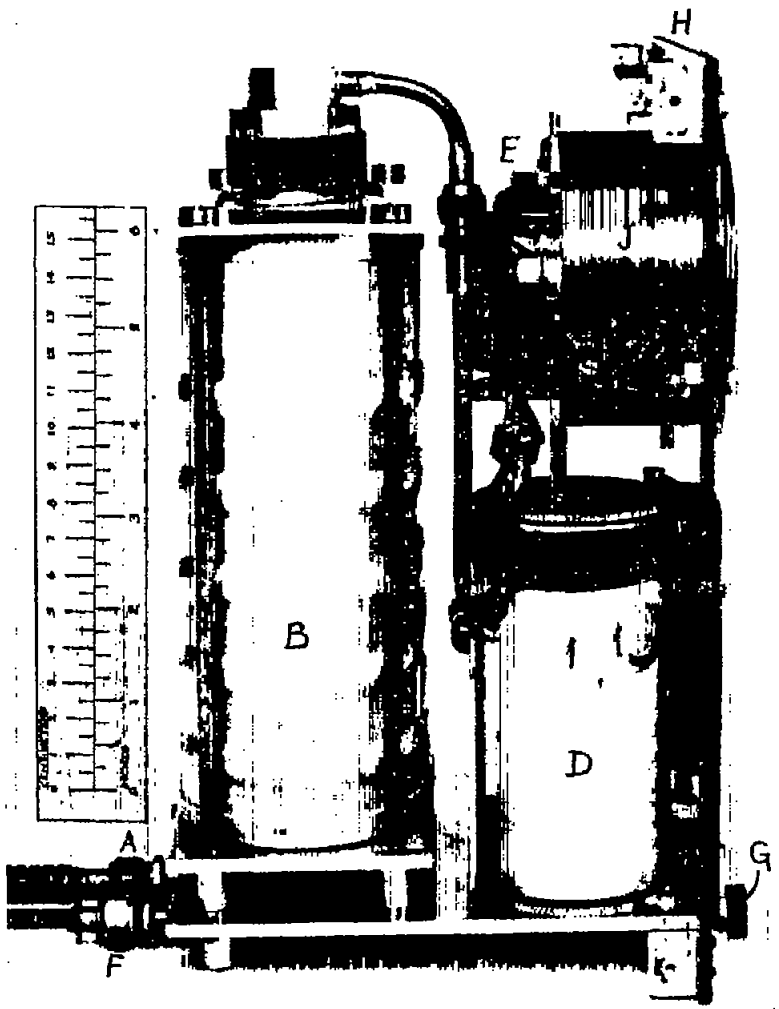

Figure 4.- Side view of modified carbon-monoxide indicator; A, air inlet; B, drying canister; D, hopcalite cell; E, flow regulator; F, air outlet; G, shut-off valve; H, manual flow adjustment; and J, millivoltmeter.

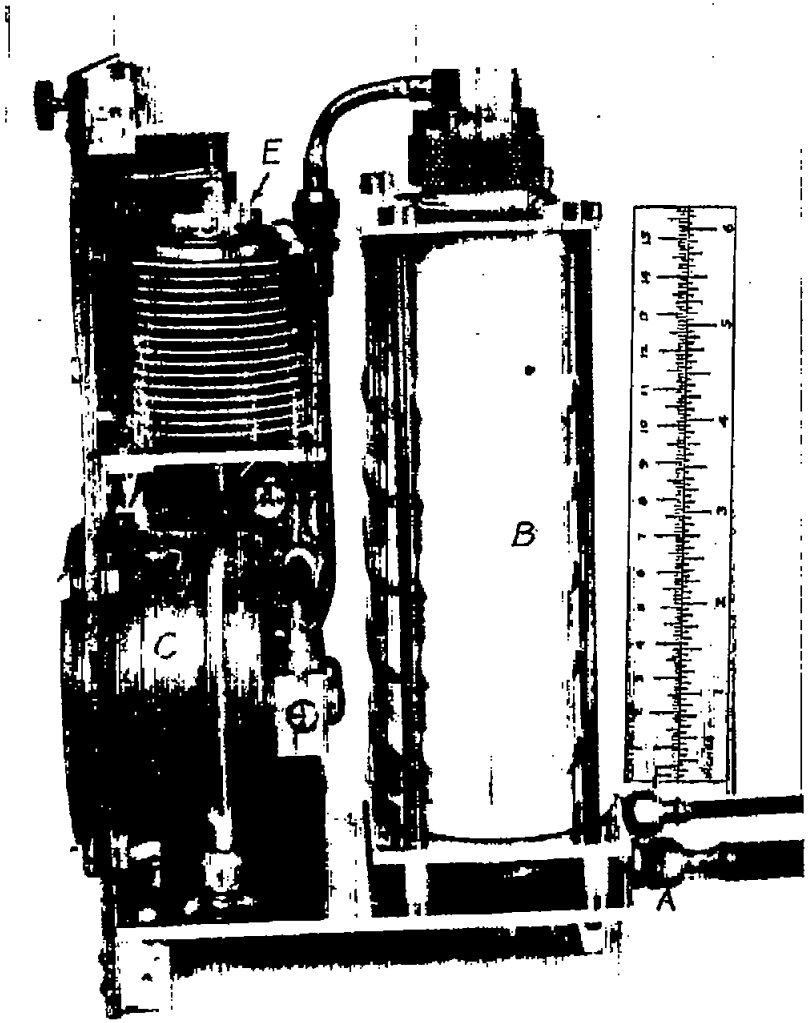

Figure 5. Side view of modified carbon monoxide indicator; A, air inlet; B, drying canister; C, flow indicator; E, flow regulator; and F, air outlet.

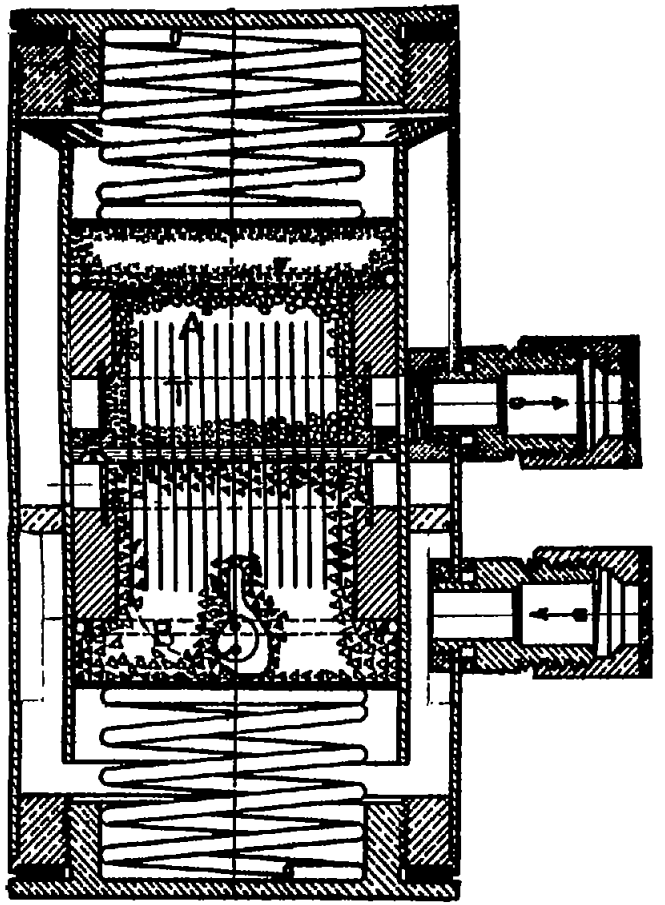

Figure 6. Diagram of hopcalite cell; A, indicates the inactive cell; B, the active cell; T, imbedded thermocouples.

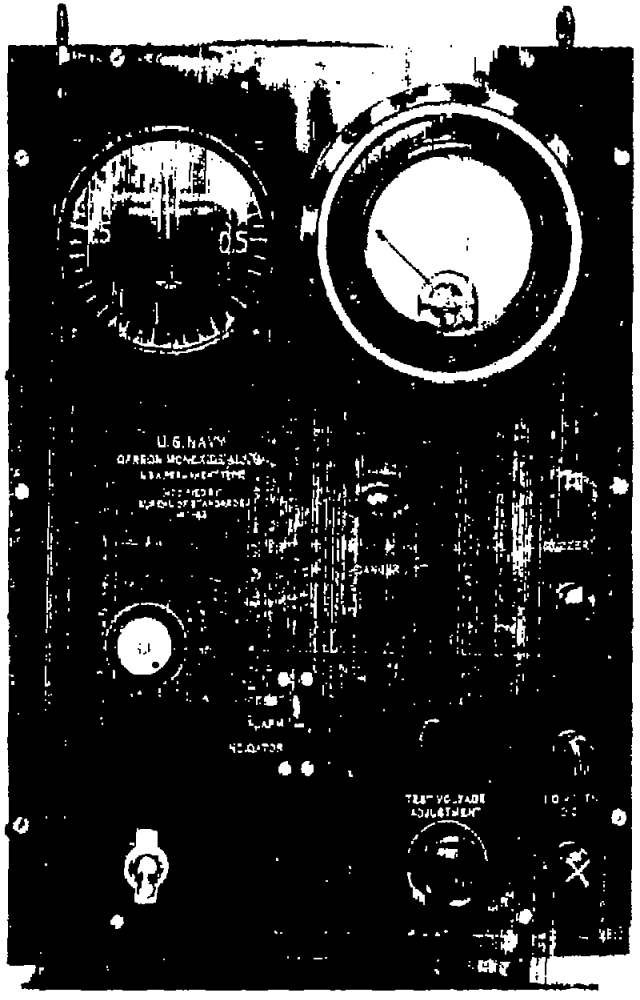

Figure 7.- Front view of carbon-monoxide indicator and alarm.

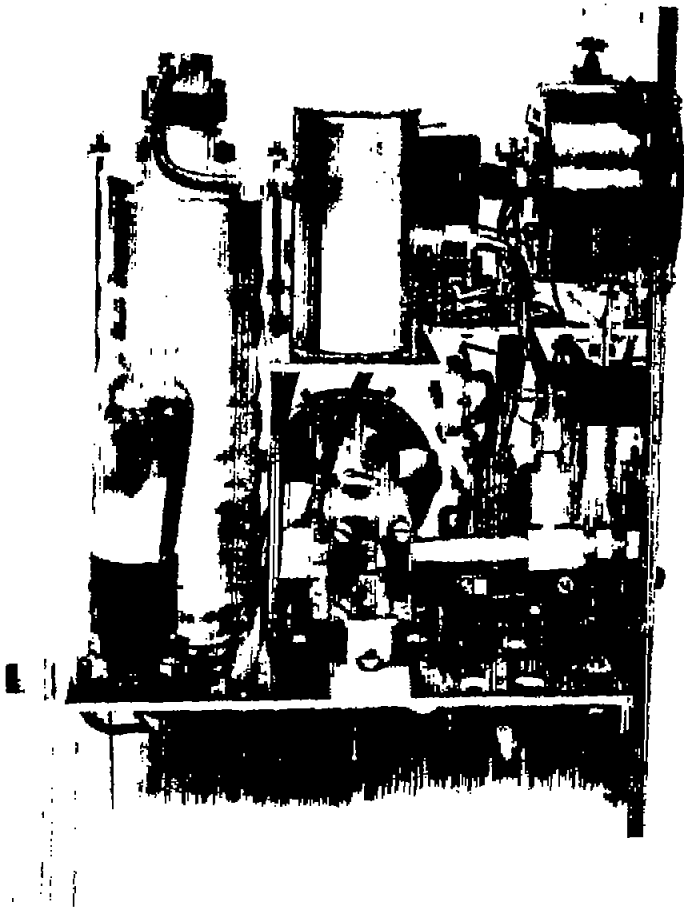

Figure 8.- Interior view of carbon-monoxide indicator and alarm

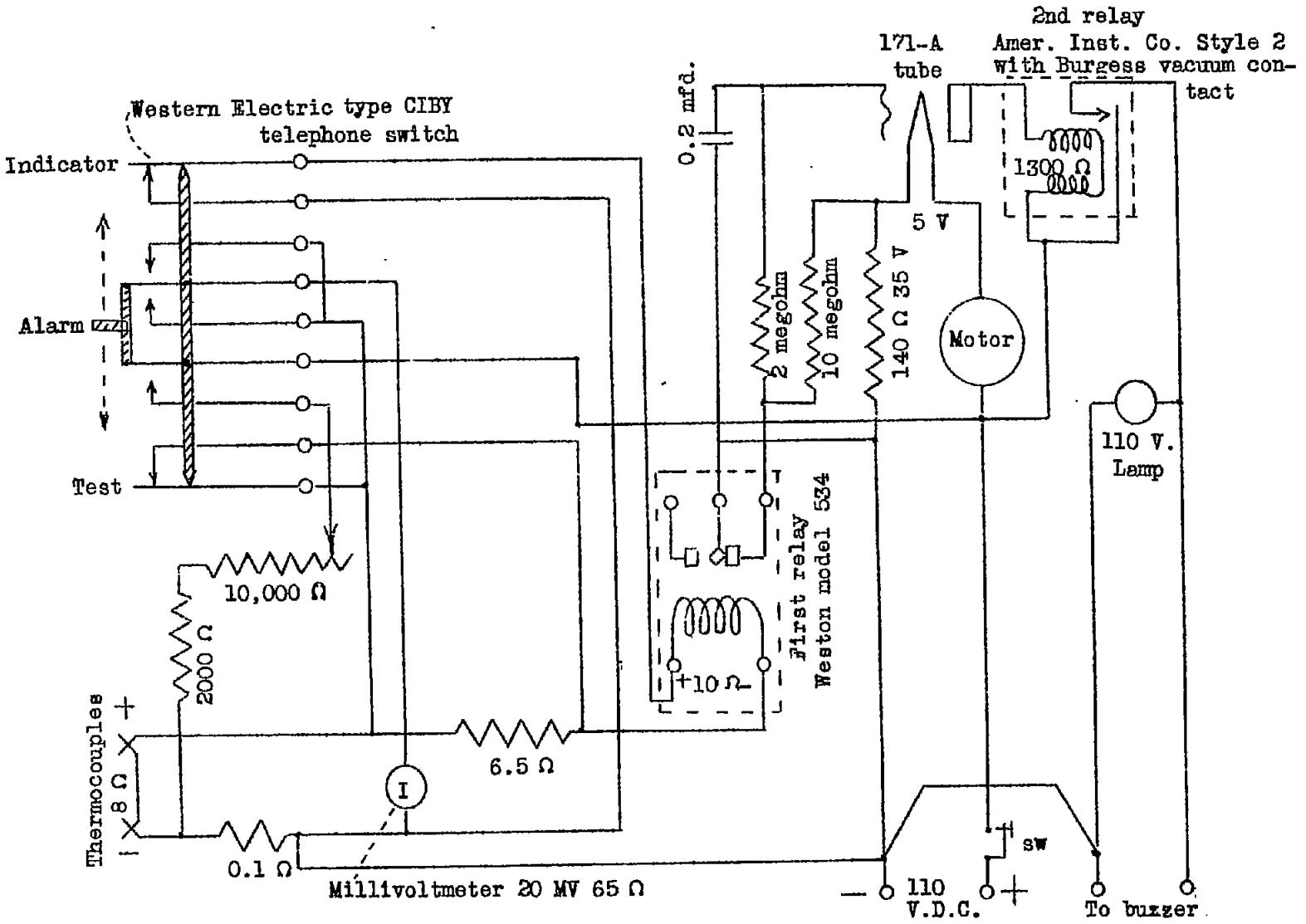

Figure 9.-Diagram of electrical connections of the alarm.

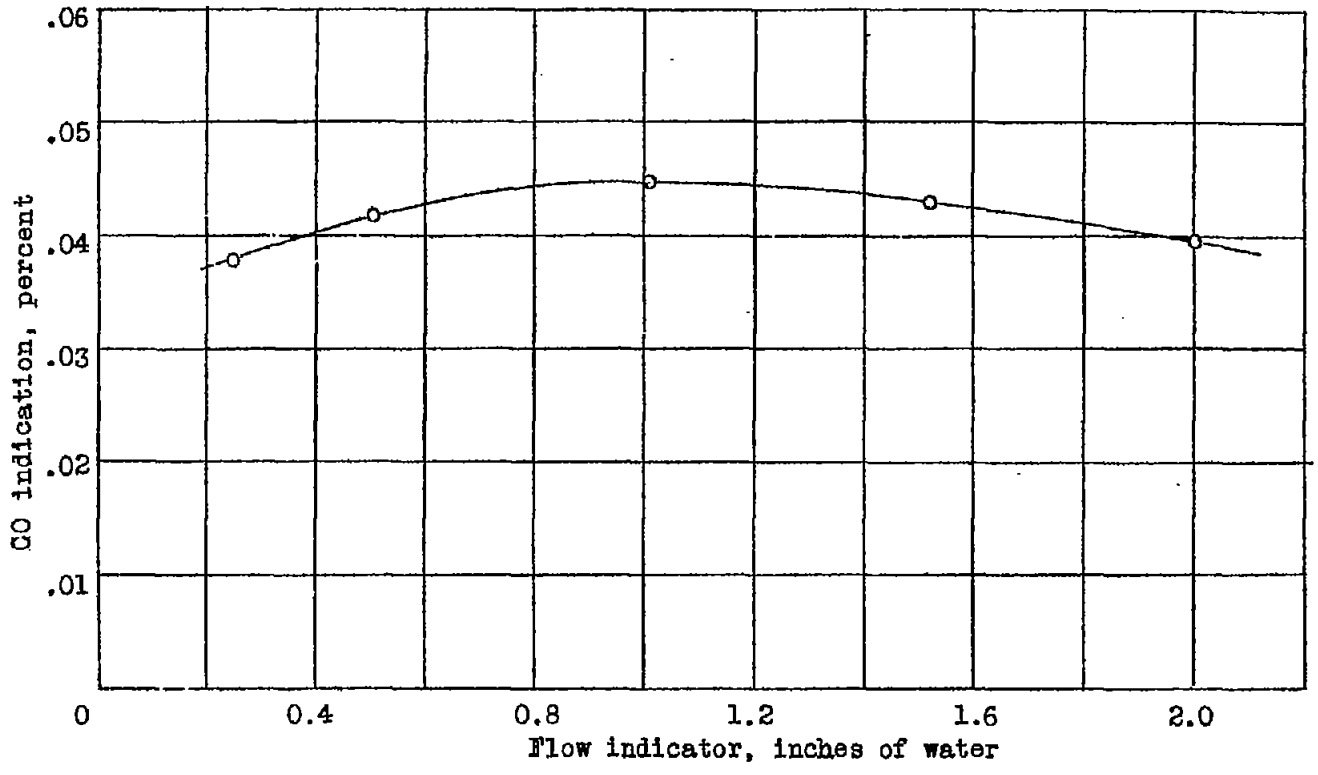

Figure 10.-Effect of rate of sampling on indication of carbon-monoxide indicator.

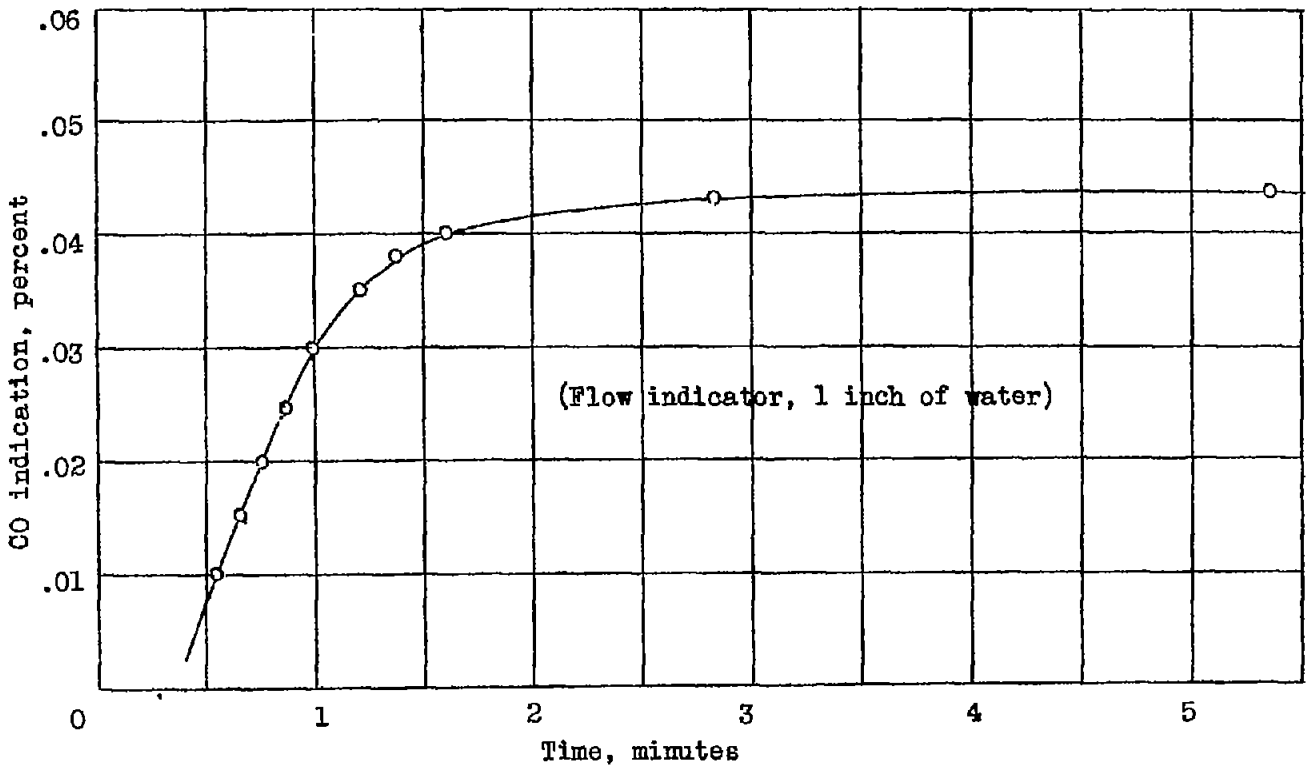

Figure 11.-Time-response characteristic of carbon-monoxide indicator.

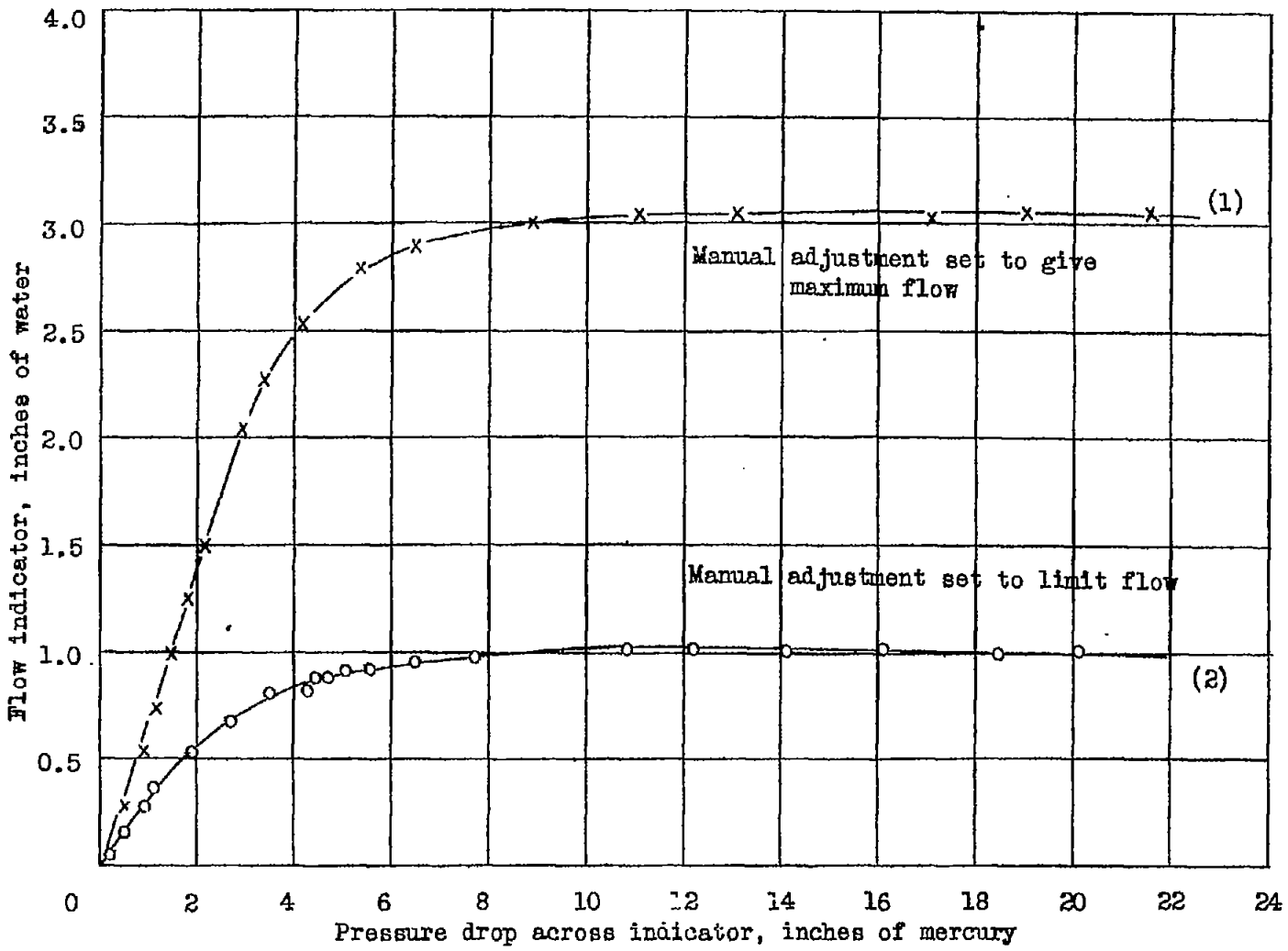

Figure 12.-Performance of automatic flow regulator.

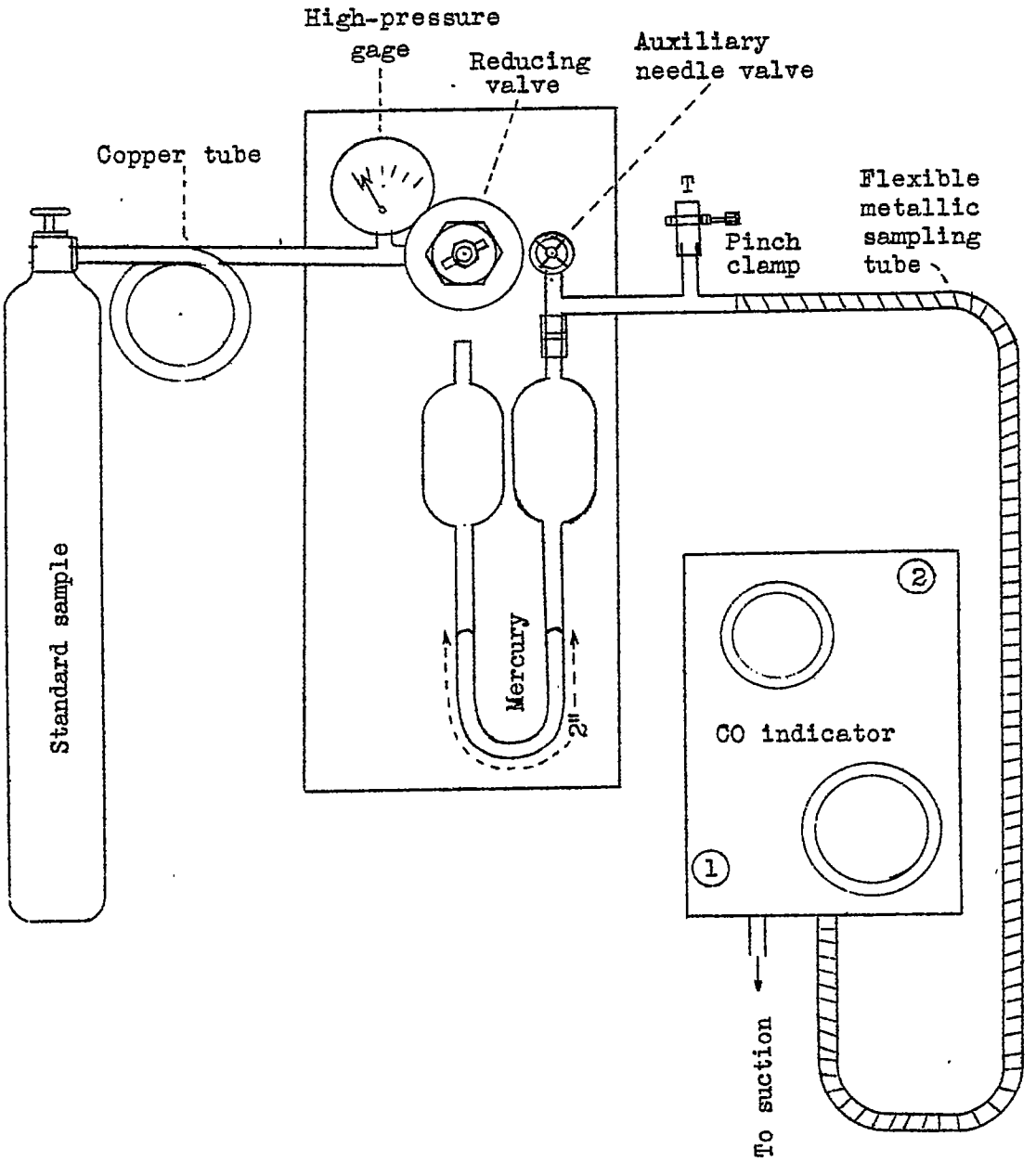

Figure 13.-Diagram of testing apparatus.