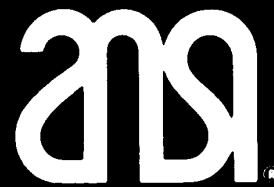


American National Standard

guide for the detection and determination of generated gases in oil-immersed transformers and their relation to the serviceability of the equipment

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IEEE Guide for the Detection and Determination of Generated Gases in Oil-Immersed Transformers and their Relation to the Serviceability of the Equipment

1. Scope and Introduction

The detection of certain gases generated in an oil-filled transformer in service is frequently the first available indication of a possible malfunction that may eventually lead to failure if not corrected. Arcing, corona discharge, low-energy sparking, severe overloading, and overheating in the insulation system are some of the mechanisms that can result in chemical decomposition of the insulating materials and the formation of various combustible and noncombustible gases. Normal operation may also result in the formation of some gases.

In a transformer, generated gases will be found dissolved in the insulating oil. They may also be found in the gas blanket above the oil or in gas-collecting devices. The detection of an incipient fault, if present, involves an evaluation of the amount of generated gas present and the continuing rate of generation. An indication of the source of the gases and the kind of insulation involved can sometimes be gained by determining the composition of the generated gases.

The purpose of this guide is to describe the details and procedure for the gas analysis of gas from gas spaces or gas-collecting devices and for gas dissolved in the oil. Experience with the guide will assist the operator in determining which procedure, or combination of procedures, best suits his needs. Several factors are involved, such as the type of oil preservation system; the type and frequency of his sampling program; and the analytical facilities at his disposal. However, whether used separately or as complements to one another, the procedures disclosed in this guide all provide the operator with positive and useful information concerning the serviceability of the equipment.

This guide covers:

- (1) The calibration and use of field instruments for detecting and estimating the amount of combustible gases present in gas blankets above oil, or in gas detector relays.
- (2) The use of fixed instruments for the detection and determination of the quantity of combustible gases present in gas blanketed equipment.
- (3) Procedures for obtaining samples of gas and oil from the transformer for laboratory analysis.
- (4) Laboratory methods for analyzing the gas blanket and the gases extrated from the oil.
- (5) Interpretation of results in terms of transformer serviceability.
- (6) A bibliography.

2. The Calibration and Use of Field Instruments for Detecting and Estimating the Amount of Combustible Gases Present in Gas Blankets Above Oil, or in Gas Detector Relays

Many of the gases generated by a possible malfunction in an oil-filled transformer are combustible. The on-site detection and estimation of combustible gases in the transformer in the field using a portable combustible gas meter can be the first and the easiest indication of a possible malfunction, and may form the basis for further testing or an operating decision.

2.1 Scope.

2.1.1 This method covers the detection and estimation of combustible gases in the gas blanket above the oil or in gas detector relays in transformers using portable field instru-

ments. It is only applicable to transformers using mineral oil as the dielectric fluid. Gases dissolved in the oil and noncombustible gases are not determined. A method of calibrating the instruments with a known gas mixture is included.

2.1.2 This method affords an estimate of the total combustible gases present in a gas mixture. If a more accurate determination of the total amount of combustible gases or a quantitative determination of the individual components is desired, a laboratory analytical method using a gas chromatograph or mass spectrometer should be used.

2.2 Summary of Method.

2.2.1 A sample of gas is diluted with a fixed ratio of air and introduced into the meter at a pressure of approximately one atmosphere. Any combustible gases present are catalytically oxidized on the surface of an incandescent platinum alloy wire which is an element of a Wheatstone bridge. When combustible gases oxidize on the surface they increase the temperature of the element which changes its resistance and upsets the balance of the bridge.

The change in the resistance of the indicating elements in the bridge circuit is indicated on a meter which is usually calibrated to read in percent total combustible gas.

2.3 Apparatus.

2.3.1 Portable combustible gas meter¹ consisting of the following components:

(1) Platinum alloy catalytic oxidizing elements incorporated in a Wheatstone bridge circuit complete with a suitable battery and controls for balancing and voltage adjustment.

(2) A milliamper meter preferably calibrated to read directly in percent total combustible gases.

(3) Gas mixing device for mixing air and sample gas at fixed ratios.

2.3.2 Standard reference gas.

2.3.2.1 The standard reference gas shall be a mixture of methane and nitrogen, with the

methane content usually between 2 and 3 percent. The methane content should be known to the nearest 0.1 percent.

2.4 Safety Precautions.

2.4.1 Gases generated in transformers can be explosive. The combustible gas meter should, therefore, be equipped with a flame arrester. Air should be used to dilute the sample gas to avoid the possibility of an explosion. Never use pure oxygen for this purpose. Strict precautions should be observed when sampling the gases from the transformer.

2.5 General Considerations.

2.5.1 In this method it is essential that sufficient oxygen be present in the gas mixture to oxidize the combustible gases. Since the gas blanket in a transformer is usually an inert gas, it is necessary to dilute the sample gas with a known amount of air. This is usually accomplished by either introducing air and the sample gas into the instrument in known ratios through fixed orifices, or by mixing known quantities of air and sample gas externally by displacement over water before introduction into the instrument. The working range of these instruments is between the low limit of sensitivity and about the lower explosive limit. They generally read off scale at the high end between the lower explosive limit and the upper explosive limit, and may indicate zero when the combustible gas content is above the upper explosive limit.

2.5.2 Contamination on the surface of the platinum alloy elements can seriously impair the sensitivity and response of the meter. This loss of response does not affect the normal balancing of the bridge circuit and is not detected by an electrical check of the instrument. It is, therefore, essential to check and calibrate the instrument frequently against a standard combustible gas mixture.

2.5.3 Since each combustible gas has its own individual instrument response, the values determined by an instrument are dependent upon the kind of combustible gas used for calibration. In order to permit interlaboratory comparisons of results, a mixture of methane in nitrogen has been selected as the standard calibrating gas mixture.

NOTE: Detector element fouling generally impairs the instrument's response to hydrocarbon gases, including methane, but has little effect on response to hydrogen. A comparison of the results of analyses of known mixtures of methane in nitrogen and hydrogen

¹The following commercial instruments have been found to be satisfactory: Davis Vapometer Model MS-1, available from Scott Aviation-Davis Products, 225 Erie Street, Lancaster, NY 14086. J. W. Portable Indicator Model SS-P, available from Johnson-Williams Division of Bacharach Industrial Instrument Company, 2300 Leghorn St., Mountain View, CA, Portable Fault-Gas Detector Model A, available from McGraw-Edison, Power Systems Division, Canonsburg, PA.

in nitrogen can, therefore, be employed to indicate the degree of detector element fouling.

2.6 Calibration.

2.6.1 Prepare the instrument for operation and make zero balance and voltage adjustments in accordance with the instructions of the instrument manufacturer and the procedure, 2.7.

2.6.2 Mix the standard reference gas with air and introduce it into the meter in exactly the same manner as used for the sample gas from the transformer.

2.6.3 Turn the calibration adjustment so the meter indicates the known methane content of the reference standard when the air and reference gas mixture is being tested. Purge the meter with air to remove traces of reference gas and proceed as in 2.7.

2.7 Procedure.

2.7.1 Prepare the instrument for operation in accordance with the instrument manufacturer's instructions. This should normally include a warmup period to allow the battery voltage to stabilize, a voltage adjustment, and an instrument balance or zero adjustment.

2.7.2 Calibrate the instrument against the standard methane mixture following the procedure in 2.6. The frequency of calibration required for individual instruments can be determined by experience. Low readings because of contamination on the platinum elements can only be detected by a check with a gas of known composition. In any case of doubt, the instrument should be recalibrated.

2.7.3 If the instrument has a range switch or more than one dilution orifice, set for maximum range or dilution to avoid damage to the instrument. Purge the instrument so it is free of gas from previous tests.

2.7.4 Introduce the mixture of air and sample in accordance with instructions of the instrument manufacturer. The flow rate should be moderate and reproducible. The pressure of gas in the oxidation chamber should be atmospheric and the temperature should be above the dew point of the gas being tested to prevent condensation of moisture on the oxidizing elements.

2.7.5 Read the percent combustible gas indicated on the meter. If the reading is low, change to a lower range or change the orifice to one admitting less dilution air. If the instrument goes momentarily off scale on the high side and then returns to zero, the combustible

gas content is probably above the upper explosive limit. This can be verified by additional dilution of the sample gas with air to bring the combustible gas content within the range of the instrument.

2.7.6 Recheck the instrument's zero balance and voltage adjustments.

2.7.7 Report reading in percent to the nearest small-scale division.

2.7.8 After use, purge the instrument to remove sample gas in order to minimize corrosion and eliminate contamination.

3. The Use of Fixed Instruments for the Detection and Determination of the Quantity of Combustible Gases Present in Gas-Blanketed Equipment

The reliability of sealed transformers with a gas space over the oil can be enhanced by monitoring the gas space using self-contained, fixed mounted instruments. These instruments detect and determine the quantity of combustible gases as well as sound an alarm when the combustible gases exceed a predetermined level. Optional recorders can also be used to provide a daily record of the combustible gases present.

3.1 Scope.

3.1.1 This method covers the detection and determination of combustible gases in the gas space above the oil in transformers using fixed instruments and sounding an alarm when the combustible gases exceed a predetermined level that is considered to be indicative of pending trouble.

3.1.2 This method affords a quantitative measurement of the total combustible gases present in the transformer gases. If the amount of the individual gas components is desired, a laboratory analytical method using a gas chromatograph or mass spectrometer should be used.

3.2 Summary of Method.

3.2.1 At least two somewhat related methods are employed.

3.2.1.1 The first type of gas monitor continually compares the thermal conductivity of the transformer gas with that of pure

nitrogen and is suitable for any transformer of the closed type with a gas space above the transformer oil.

3.2.1.1.1 The transformer gas is continually circulated through one section of a Wheatstone bridge and returned to the transformer. The other section of the bridge contains pure nitrogen and is balanced against the transformer gas.

3.2.1.1.2 When combustible gases are produced in the transformer, they mix with the transformer gas and increase the thermal conductivity of the transformer gas. The increase in the thermal conductivity of the transformer gas unbalances the Wheatstone bridge and is proportional to combustible gases as indicated on a meter.

3.2.1.2 The second type of gas monitor continuously samples the transformer gas at fixed intervals and burns any combustible gases present to provide a measure of the combustible gases. This type of monitor is used only on transformers with a positive pressure of nitrogen over the oil.

3.2.1.2.1 At a fixed interval (usually 24 h) a sample of the transformer gas is pumped from the unit, mixed with air, and passed over a heated platinum sensor of a Wheatstone bridge. Any combustible gas in the sample is burned. This raises the temperature of the sensor and unbalances the bridge which was balanced against a second platinum sensor in air. The degree of unbalance is proportional to the amount of combustible gases present in the transformer gas as indicated on a meter.

3.2.1.3 A relay is operated in conjunction with the percent gas meter so that when the combustible gases exceed a preset value (usually 1 percent) the relay sounds an alarm.

3.2.1.3.1 The alarm relay can be reset at a higher combustible gas level once the initial 1 percent level has been reached. The time to reach this new level will give a measure of the rate of gas formation.

3.2.1.3.2 All units that have sounded an alarm should be checked with a portable gas meter to verify the combustible gas level, or the gas should be sampled for complete analysis by a gas chromatograph or mass spectrometer.

3.3 Significance.

3.3.1 The combustible gas monitor provides a means for the continuous detection of combustible gas and the determination of the rate

of its formation over the oil resulting from incipient internal fault in transformers. If the level of combustible gases reaches a preset limit an alarm is actuated, this warning of pending trouble.

3.4 Apparatus.

3.4.1 Fixed combustible gas apparatus² consisting generally of the following components.

(1) A Wheatstone bridge circuit capable of accurately determining changes in thermal conductivity of gases, with controls for balancing and voltage adjustment.

(2) A milliamper meter calibrated to read directly in percent total combustible gases.

3.4.2 The standard reference gas shall be made in accordance with manufacturers' recommendations.

3.4.3 *Optional Recorder.* Provision is made on the fixed combustible gas apparatus to install a recorder to give a permanent daily record of changes in combustible gas concentration.

3.5 Safety Precautions. Gases generated in transformers can be explosive. Strict precautions should be observed when sampling the gases from transformers.

3.6 Calibration. The instruments shall be calibrated in accordance with the manufacturers' instruction guide.

3.7 Maintenance.

3.7.1 At the time of installation and each year thereafter, the equipment should be standardized to be sure the monitor is operating properly.

3.7.2 For restandardization and repairs, the operator should follow the manufacturers' instruction guide.

4. Procedures for Obtaining Samples of Gas and Oil from the Transformer for Laboratory Analysis

4.1 Gas Samples for Laboratory Analysis.

4.1.1 *Gas Blanket.* It has become common practice to extract samples of gas from the

² A commercial instrument found to be satisfactory is TCG Fault-Gas Monitor, available from McGraw-Edison Co, Power Systems Division, Canonsburg, PA.

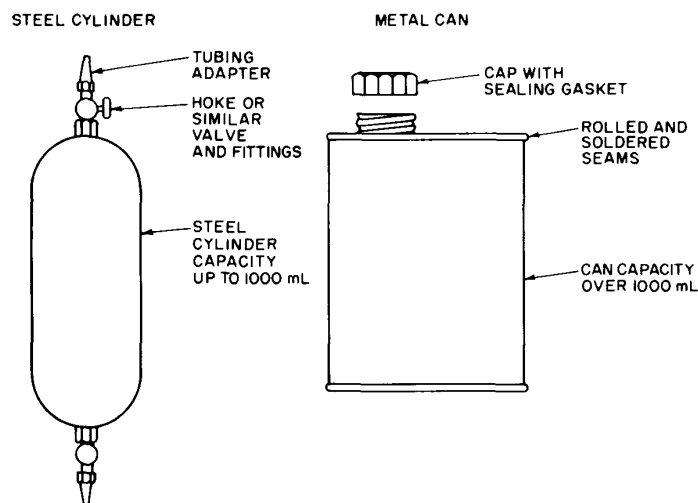


Fig 1
Metal Sample Containers

gas blanket above the oil in sealed transformers, for submission to the laboratory for quantitative analysis. This may be conveniently performed in accordance with ASTM D2759, Standard Method for Sampling Gas from a Transformer under Positive Pressure, being careful to obtain a representative sample.

4.1.2 Gas Collection Device. Transformers not having a gas space may be equipped with a gas collector relay which is connected to the highest point of the transformer in order to collect the gases which may form in the unit. A gas sample may be taken from such a device by connecting a gas-tight (or precision ground) glass syringe through a short length of plastic tubing and a three-way stopcock to the device. To do so, flush the tubing, stopcock, and syringe by valving the gas from the relay to the syringe. (See ASTM D923, Tentative Method for Sampling Gas from a Transformer by Syringe.)

4.1.3 Gas Dissolved in Oil. Gas decomposition products of electric insulating oil and solids are soluble in oil to varying degrees depending on composition.

In the case of oil-filled (diaphragm or conservator) transformers, until sufficient gas has accumulated to operate a gas detector relay, there is no gas in the transformer tank above the oil; hence, the only gas available for analysis is that dissolved in the oil.

Sample size requirements are a function of the sensitivity of the apparatus in use and the amount of dissolved gas present. Samples as small as 1 ml or as large as 1000 ml have proven to be satisfactory with current technology.

4.1.4 Transport and Direct Sampling Containers. It is essential that the oil sample be representative of oil within the equipment. Following are recommendations for the acceptance criteria for transport and direct sampling containers.

4.1.4.1 Transport Containers. Transport containers should meet the leak criterion in 4.1.4.2. They should be suitable for shipment by mail and by any freight carrier. It cannot be overemphasized that the results of the analysis by this method may dictate judgments on the serviceability of power equipment; therefore, all precautions should be taken to ensure the safe delivery of good uncontaminated samples.

Several types of containers are presently used. They are listed below.

- (a) calibrated stainless steel cylinders (Fig 1)
- (b) flexible metal cans (Fig 1 — one suggested type)
- (c) syringes (see ASTM D923)
- (d) glass bottles.

The optimum method of filling the can and

sampling the contents of the can are still under development.

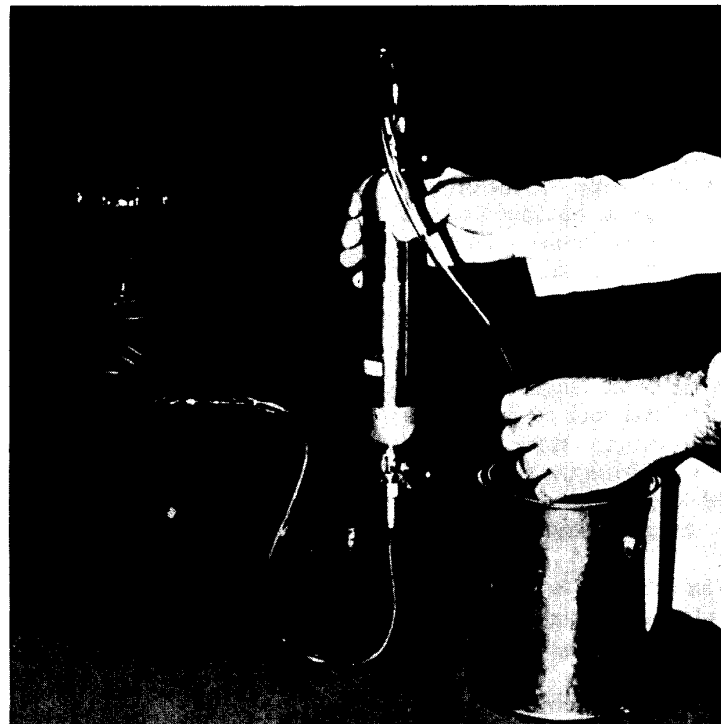
4.1.4.2 Leak Acceptance Criterion for Transport Containers. The introduction or loss of gases to or from the sample during sampling, transport to the analytical laboratory, and transfer to the extraction process should not exceed 0.35 percent of the hydrogen or helium content of a standard sample per day — in lieu of other procedures meeting this criterion, ASTM D923 is recommended, but subject to the above leak criterion.

4.1.4.3 Direct Sampling or Transfer Containers. Glass syringes are the direct sampling containers of choice where the oil is taken directly from the equipment and introduced into the extraction device. They are also recommended for transferring oil or gas samples from transport containers (4.1.4.1) as shown

in Fig 1. Syringes must also conform to the leak criterion in 4.1.4.2 and be used in accordance with ASTM D923.

4.1.4.4 Oil Sampling Using Metal Bottles — Oil Sampling Procedure. Tubing adaptors are attached to each end of the threaded ends of the shutoff valves of the stainless steel sampling bottle. Two lengths of flexible polyvinyl chloride tubing are attached to the tubing adaptors. Before attaching the polyvinyl chloride tubing to the main sample valve, flush the valve into a scrap-oil container. One end of the tubing is attached to the oil sampling valve of the transformer and the open end of the other piece of tubing is placed in a scrap-oil container. Both valves of the sample bottle are opened and then the main valve of the transformer is opened. The sample bottle must be held in the vertical position (Fig 2).

Fig 2
Oil Sampling with a Metal Bottle



The oil will gradually fill the oil container from the bottom and overflow through the top into the scrap-oil container. Continue overflowing the oil until no more bubbles can be seen through the plastic tubing and until two quarts of oil have been collected in the scrap-oil container. Close the top valve of the sample bottle and allow oil pressure to build up, then close the bottom valve of the sample bottle and finally the main transformer valve.

NOTE: Oils having a high degree of gas saturation may account for bubbles if there is a significant change in the temperature in the sample in or during transit. (See 5.1.2.4.4.)

5. Laboratory Methods for Analyzing the Gas Blanket and the Gases Extracted from the Oil

5.1 Gas Extraction and Analysis.

5.1.1 Gas Blanket Sample. The sample of the gas blanket may be submitted directly to analysis as described in 5.2.3 except that the results will be reported as percentages.

5.1.2 Gas Extraction from Oil Sample by Expansion in an Evacuated Flask.

5.1.2.1 Scope. This method covers the extraction and measurement of gases dissolved in electrical insulating oil having a viscosity of 20 centistokes (100 Saybolt Universal Seconds) or less at 40°C (104°F) and their containment for quantitative analysis. Any noncondensable gas may be determined.

5.1.2.2 Summary of Method. Dissolved gases are extracted from a sample of oil by introduction of the oil into a pre-evacuated known volume. The evolved gases are compressed to atmospheric pressure and the total volume measured.

5.1.2.3 Description of Terms. Gas content of oil by volume is the total volume of gases, corrected to 760 torr and zero degrees Celsius, contained in a given volume of oil, expressed as a percentage.

5.1.2.4 Apparatus.

5.1.2.4.1 Method A: A method suitable for determining the total amount of dissolved gas and the amounts of the individual dissolved gases using samples of 1 ml to 50 ml in size. (See Figs 3 and 4). Flexible polyvinyl chloride tubing terminated with a Luer fitting to accept a glass syringe and leading to a solid plug, three-

way high-vacuum stopcock lubricated with the minimum amount of high-vacuum silicone grease.

A degassing flask with a fritted glass gas dispersion inlet tube, of sufficient volume to contain up to 50 ml of oil below the inlet tube, capable of being evacuated, containing a ptfе coated magnetic spin bar, and mounted on a magnetic stirrer.

A means of measuring absolute pressure within the apparatus.

A vacuum pumping system capable of evacuating the glassware to an absolute pressure of 1×10^{-3} torr or lower.

Vacuum glassware sufficiently large compared to the volume of the oil sample, so that virtually complete degassing is obtained and the volumetric collection ratio is as large as possible. A 500 ml gas collecting flask has been found suitable.

High-vacuum valves or stopcocks employing the minimum necessary amounts of high-vacuum stopcock grease are used throughout the apparatus.

A gas collection tube calibrated in 0.01 ml divisions capable of containing up to 5 ml of gas, terminated with a silicone rubber retaining septum. A suitable arrangement is shown in Fig 5.

A reservoir of mercury³ sufficient to fill the collection flask and collection tube.

5.1.2.4.2 Determination of apparatus collection ratio. The apparatus shall be carefully checked for vacuum tightness of all joints and stopcocks.

The volume of the total extraction space V_T , and the volume of the collection space V_C , shall be measured, and the ratio $\left(\frac{V_C}{V_T + V_{cyl}}\right) - V_0$ where V_0 is the volume of oil sample, V_T is the total internal volume of extraction space, and V_{cyl} is the volume of calibrated stainless steel cylinder (if a syringe is used this number is zero) shall be calculated as the volumetric ratio.

The degassing efficiencies for each individual component gas shall be calculated using the formula

$$E_i = \frac{1}{1 + \left[\frac{K_i \times V_0}{(V_T + V_{cyl}) - V_0} \right]}$$

³ Suitable handling precautions shall be observed.