IEEE Guide for Moisture Measurement and Control in SF_6 Gas-Insulated

Sponsor

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Abstract: Guidelines for moisture level measurement, moisture data interpretation, and moisture control in gas-insulated transmission class equipment (GIE) are provided.
Keywords: circuit breakers, gas-insulated equipment (GIE), gas-insulated substations (GIS), moisture measurement, SF_6

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Introduction

(This introduction is not part of IEEE Std 1125-1993, IEEE Guide for Moisture Measurement and Control in SF_6 Gas-Insulated Equipment.)

The objectives of this guide are to introduce the importance of moisture in the design, manufacture, installation, operation, and maintenance of transmission class gas-insulated equipment and to provide guidance for measurements of moisture in gas-insulated equipment.

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IEEE Guide for Moisture Measurement and Control in SF_6 Gas-Insulated Equipment

1. Overview

Moisture measurement and control constitute a major part of an effective maintenance program for gas-insulated equipment (GIE). Moisture, particularly in the liquid phase, affects the dielectric withstand strength of GIE [B9].[1] Therefore, moisture in GIE shall be maintained at a level such that it does not condense into liquid for the entire range of the expected operating temperatures. Additionally, excessive moisture in the enclosed equipment accelerates the formation of hydrofluoric (HF) acid, a result of reactions between SF_6 arc by-products and water [B2], [B6]. Because of the importance of moisture in controlling insulation strength and aging mechanisms of the epoxy insulating spacers, most users periodically measure moisture levels in their SF_6 insulated equipment. However, results of a North American survey conducted in 1984 by the IEEE Insulated Conductors Committee indicate that utility personnel have experienced difficulties in carrying out moisture measurement and interpretation in GIE [B6], [B3]. The experience has shown that although hygrometry is an established science, techniques and procedures for moisture measurement in GIE are not well understood. As a result, there is considerable confusion among engineers and field personnel on how to properly measure moisture (particularly under high-pressure conditions), interpret the results, and control the moisture levels.

Compounding the problem of moisture measurement in GIE is the fact that moisture inside the GIE system can exist in either the vapor or adsorbed phase on the surface of the enclosure, or in the absorbed phase inside the polymeric solid insulator. The distribution of moisture in the various phases can significantly affect the dielectric strength and the measurement results. For example, moisture measurements taken in the winter would tend to be lower than moisture measurements taken in the summer, since more surface-adsorbed water exists during periods of low temperature. Elucidation of the moisture sources and migration phenomena is the key to designing an effective moisture measurement and control program.

The objective of this guide is to provide adequate information about the techniques and know-how needed to conduct a successful moisture measurement and control program for GIE.

2. Scope

This document establishes guidelines for moisture level measurement, moisture data interpretation, and moisture control in gas-insulated transmission class equipment.

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[1]The numbers in brackets correspond to those of the bibliography in clause 11.

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3. Purpose

Because of the importance of moisture in the design, manufacture, installation, operation, and maintenance of GIE, guidelines are necessary to establish an acceptable range of moisture levels depending on equipment design, measurement procedures, and data interpretation.

The purpose of these guidelines is to provide guidance and promote understanding among users of GIE. More specifically, the objective is to communicate general knowledge and sufficient understanding so as to ensure successful operation of the equipment.

4. Definitions

4.1 parts per million by volume (PPMV): One million times the ratio of the volume of water vapor present in the gas to the total volume of the gas (including water vapor).

4.2 parts per million by weight (PPMW): One million times the ratio of the weight of water vapor present in the gas to the total weight of the gas (including water vapor).

4.3 dew point: The temperature at which the water vapor in the gas begins to condense, expressed in degrees Fahrenheit (ºF) or Celsius (ºC).

4.4 relative humidity (RH): The ratio between the amount of water vapor in the gas at the time of measurement and the amount of water vapor that could be in the gas when condensation begins, at a given temperature.

5. Conversion of measurement units

Moisture measurements in GIE are generally reported in PPMV, PPMW, or dew point in ºF or ºC since most available instrumentation is calibrated in these units. Relative humidity, expressed in percent, is often used to represent moisture content in the gas, but it is rarely measured directly by an instrument. Instrumentation to measure PPMV, PPMW, and dew point is discussed in the following subclauses.

5.1 Parts per million by volume (PPMV)

PPMV is the most commonly used system of units in North America. If the moisture level is 300 PPMV, for 1 ft^3 (28.32 L) of SF_6 in the system, there are $300 \cdot 10^{-6}$ ft^3 (0.0085 L) of water vapor at the pressure at which the system is maintained. The PPMV level is independent of the pressure. For example, if the SF_6 gas is at 304 kPa (3 atm) pressure and has a moisture content of 300 PPMV, it still contains 300 PPMV of moisture when the system pressure is changed to 101 kPa (1 atm). The moisture content in absolute number of water molecules decreases if the pressure decreases, but the PPMV remains the same.

5.2 Parts per million by weight (PPMW)

If the moisture level is 37 PPMW (300 PPMV) for each pound (0.45 kg) of SF_6 in the system, there are $37 \cdot 10^{-6}$ lb ($17 \cdot 10^{-6}$ kg) of water vapor.

5.3 Conversion from PPMV to PPMW

The molecular weight of SF_6 is 146. The molecular weight of water vapor is 18. A given volume of SF_6 weighs 146/18, or 8.1 times the same volume of water vapor. Conversely, 1 g of water vapor occupies 8.1

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times the volume of 1 g of SF_6 at the same temperature and pressure. Therefore, the conversion factor for PPMV to PPMW is 8.1, assuming that the system is filled with essentially pure SF_6.

Examples:

300 PPMW · 8.1 = 2430 PPMV
2430 PPMV/8.1 = 300 PPMW

5.4 Dew point

If the moisture content is known in PPMV, to find the dew point in °C the water vapor pressure is calculated by multiplying the PPMV measurement by the system absolute pressure to obtain the partial pressure of the water vapor. Table 1 shows the relationship between temperature and saturated water vapor pressure. If the water vapor partial pressure reaches the saturation vapor pressure at the corresponding temperature shown in table 1, the water vapor begins to condense.

Table 1—Pressure of saturated aqueous vapor in mmHg* for temperatures of –59 – +109 °C

Temp. °C	0	1	2	3	4	5	6	7	8	9
–50	0.029	0.026	0.023	0.020	0.017	0.015	0.013	0.012	0.010	0.009
–40	0.096	0.086	0.076	0.068	0.060	0.054	0.048	0.042	0.037	0.033
–30	0.288	0.259	0.233	0.209	0.188	0.169	0.151	0.135	0.121	0.108
–20	0.783	0.712	0.646	0.585	0.530	0.480	0.434	0.392	0.354	0.319
–10	1.964	1.798	1.644	1.503	1.373	1.252	1.142	1.041	0.947	0.861
–0	4.580	4.220	3.887	3.578	3.291	3.025	2.778	2.550	2.340	2.144
0	4.58	4.92	5.29	5.68	6.10	6.54	7.01	7.51	8.04	8.61
10	9.21	9.85	10.52	11.24	11.99	12.79	13.64	14.54	15.49	16.49
20	17.55	18.66	19.84	21.09	22.40	23.78	25.24	26.77	28.38	30.08
30	31.86	33.74	35.70	37.78	39.95	42.23	44.62	47.13	49.76	52.51
40	55.40	58.42	61.58	64.89	68.35	71.97	75.75	79.70	83.83	88.14
50	92.6	97.3	102.2	107.3	112.7	118.2	124.0	130.0	136.3	142.8
60	149.6	156.6	164.0	171.0	179.5	187.8	196.3	205.2	214.4	224.0
70	233.9	244.2	254.0	266.0	277.4	289.3	301.6	314.4	327.6	341.2
80	355.4	370.3	385.2	400.8	417.0	433.7	451.0	468.8	487.3	506.3
90	526.0	546.3	567.2	588.8	611.1	634.1	657.8	682.2	707.4	733.3
100	760.0	787.5	815.9	845.0	875.1	906.0	937.8	970.5	1004.	1039.

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*To convert from mmHg to Pa, multiply by 133.322.

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Example:

What is the dew point of an SF_6 system having a moisture content of 300 PPMV at gage pressure 152 kPa (22 psig)?
Pressure = $300 \cdot 10^{-6} \cdot (152 + 101) = 0.0759$ kPa
Use table 1 to find the dew point by converting 0.0759 kPa to mmHg by dividing by 0.1333.
The result, 0.57 mmHg, has a dew point of approximately –23 ºC

NOTE—To find the dew point using psig, use the following formula:

Pressure = $300 \cdot 10^{-6} \cdot (22 + 14.7) \cdot 51.7 = 0.57$ mmHg

The 51.7 multiplier is used to convert the pressure from psia to mmHg for use with table 1.
(760 mmHg = 14.7 psi, so 1 psi = 760/14.7 = 51.7 mmHg)

The pressure at which the measurement was taken now enters the conversion calculation. For example, if the gage pressure was 600 kPa (87 psig) when the same moisture reading of 300 PPMV was taken, the dew point is now –12 ºC. Thus, when converting and comparing PPMV or PPMW and dew point readings, the pressure at which the reading is recorded is extremely important.

Many instruments that measure dew point operate at the system pressure. Instruments that measure PPMV are designed for use at pressures slightly higher than atmospheric pressure—gage pressure slightly above 0 kPa (0 psig) to provide gas flow for sampling. Normally, the system sampling valve is opened slightly to maintain the gas flow and take a PPMV measurement at a pressure of slightly above atmospheric pressure. This difference in instrument operation shall be taken into account when converting and comparing dew point and PPMV levels.

5.5 Relative humidity (RH) (%)

To find RH in percent, divide the water vapor partial pressure calculated in 5.4 by the vapor pressure at saturation (100% RH) at the mean gas temperature at the time of measurement. The vapor pressure at saturation is the combination of water vapor pressure and temperature at which water vapor begins to condense (from table 1). Because condensation is temperature dependent, the ambient temperature of the gas is used to determine the saturation point for the gas system.

Example:

A moisture measurement of 300 PPMV was taken at 20 ºC in a gas system at gage pressure 152 kPa (22 psig). The water vapor in a gas at 20 ºC will begin to condense when it reaches a partial pressure of 2.34 kPa (17.55 mmHg)—see table 1. At 300 PPMV, the partial pressure of water vapor is calculated (in 5.4) to be 0.0759 kPa (0.570 mmHg). Therefore,

$$RH = \frac{0.0759}{2.34} \cdot 100\% = 3.25\%$$

NOTE—In this conversion, the temperature at which the moisture measurement is taken becomes part of the conversion calculation. If the moisture measurement had been taken at 50 ºC, the RH would have been only 0.62%. This conversion helps show the importance of temperature to the moisture measurement and the importance of making comparisons of readings.

6. Measuring instruments

Several instruments are available for measuring moisture. Most of the instruments operate on one of two principles: absolute humidity or relative humidity. Both operating principles are discussed briefly in the following subclauses. Figure 1 shows the location of the moisture meter and valves in a typical moisture measurement setup.

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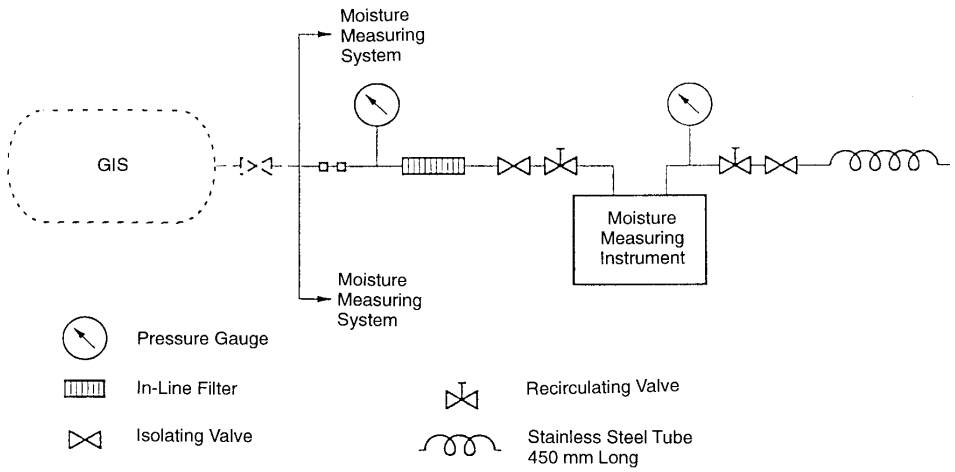


Figure 1—Location of the moisture meter and valves in a typical moisture setup

6.1 Absolute humidity instruments

Absolute humidity instruments use the chilled mirror principle. The mirror is placed in the gas to be measured and cooled until dew or fog forms on its surface. An optical electronic system regulates the cooling, and the mirror temperature at condensation is measured and indicated on a digital readout.

The instrument is supplied with a gas inlet and gas return or outlet. Stainless steel or Teflon® tubing is used for connection to the gas system. A differential pressure shall be maintained between the inlet and return to allow gas flow for proper sampling. The minimum flow rate generally is small, 1.4 ft^3/h (40 L/h), and a differential pressure of 0.293 kPa (2.2 mmHg) is required to maintain this flow rate. Special gas pumps also are available, if necessary.

An advantage of the chilled mirror hygrometer is that measurements can be taken at the system pressure. The maximum operating pressure of the instrument, with regard to the operating pressure of the system to be sampled, is about 950–1030 kPa (140–150 psig equivalent). The manufacturer recommends that measurements be taken at low pressure, if possible, because higher pressure can cause SF_6 liquefaction. The measurement unit used in this instrument is expressed directly as dew point in ºC or ºF. For example, if the working pressure is 696 kPa (101 psig) at 20 ºC, liquefaction of SF_6 takes place at -20 ºC. If the desired dew point is -18 ºC, measurement is difficult due to the proximity of the temperature which causes both the SF_6 and the moisture to liquefy. On the other hand, SF_6 at atmospheric pressure condenses at -64 ºC. Therefore, for moisture measurements taken at atmospheric pressure, only very low dew points are affected by SF_6 liquefaction.

6.2 Relative humidity hygrometers

The second type of instrumentation includes a large group of RH hygrometers that employ specially selected hydrophilic materials. When the relative humidity changes, these materials, while at ambient temperature, exchange enough moisture to regain equilibrium, and corresponding measurable changes occur in the electrical resistance, the capacitance, or the extent of electrolysis taking place. Hygrometers using aluminum oxide sensors, thin-film sensors, and silicon semiconductor sensors are typical of this type of instrumentation, and are used widely by utilities. Since the sensors usually display hysteresis and are temperature

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sensitive, frequent calibrations are required to obtain reliable operation. However, these types of hygrometers usually are simple in construction and easy to use in the field. As discussed earlier, these hygrometers usually measure the moisture content at atmospheric pressure, with the inlet connected to the GIE system [typically at 304 kPa (3 atm) of pressure or higher] being sampled and the outlet usually vented to atmospheric air. Flow rates are maintained by cracking the GIE valve slightly. The flow rate shall be maintained until the moisture reading stabilizes.

6.3 Operation

Based on experiences gained through using the instruments described in 6.1 and 6.2, the following precautions are recommended to help ensure consistent measurements:

a) Only the type of inlet and outlet tubing specified by the instrument manufacturer should be used. Stainless steel is recommended, although Teflon also is used. Rubber tubing or similar materials should never be used because moisture coming from the walls of these materials invalidates the readings.

b) Prior to assembly, the stainless steel tubing and all fittings should be absolutely clean. Oil and grease are common causes of incorrect measurements. Once assembled, the system should be leak-checked thoroughly to ensure that flow rates are maintained and atmospheric moisture cannot enter.

c) The manufacturer's instructions should be followed and the manufacturer-specified flow rates should be maintained.

d) Sufficient time should be allowed for the gas flow to provide stable readings. It takes at least 15–30 min for the reading to stabilize, even if the instrument has been properly maintained (i.e., kept dry).

   NOTE—It is important not to reduce the gas pressure in the equipment below the recommended limits for safe operation. The manufacturer's recommendations for gas sampling and moisture checks should be followed when making these measurements.

   If the instrument has been left open to ambient air (particularly in the summer during periods of high relative ambient humidity), the instrument and inlet tubing should be placed on a dry gas system for several days to dry out before any readings are taken.

e) To ensure that proper analysis can be performed, the date, ambient temperature, system operating pressure, type of instrument, sample pressure (if appropriate), and gas temperature of the GIE should be recorded when readings are taken.

f) Personnel should be aware that reactive gases may be present in contaminated systems or if arced SF_6 is present. These gases will invalidate the moisture measurements. The SF_6 arc by-products may affect certain types of hygrometers more than others.

   CAUTION—Some of these by-products may be hazardous if inhaled. A sniff test should not be used to determine the presence of by-products. The manufacturer and gas supplier handbooks should be consulted for procedures on checking for the presence of hazardous by-products.

7. Pressure and temperature effects on moisture measurements

7.1 Pressure effects

The effects of pressure on the conversion of the moisture measurements from one system of units to another is discussed in clause 5. In order to obtain accurate results, the following shall be observed.

a) The pressure dependence for the type of hygrometer used in the measurement shall be considered. For example, chilled mirror hygrometers measure dew point at system pressure. Aluminum oxide sensors, however, require a continuous flow of gas and, depending on the location of the valves, normally measure dew point at ambient pressure.

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b) If the GIE manufacturer specifies an acceptable moisture limit at system pressure, the measurement taken with the dew point hygrometer shall be converted to that unit (usually PPMV or PPMW for the appropriate pressure). Figure 2 shows a flow chart for typical unit conversion and comparison.

As the system operating pressure is increased by adding gas (provided the SF_6 being added has a low moisture content), both the PPMV and PPMW of water vapor decrease. Therefore, the moisture level in PPMV or PPMW is lower at operating pressure than after being filled to 101 kPa (1 atm). However, the partial pressure of the water vapor is higher, so water begins to condense at a higher temperature. Thus, the higher the operating pressure of the GIE, the lower the water vapor content that can be tolerated in the system.

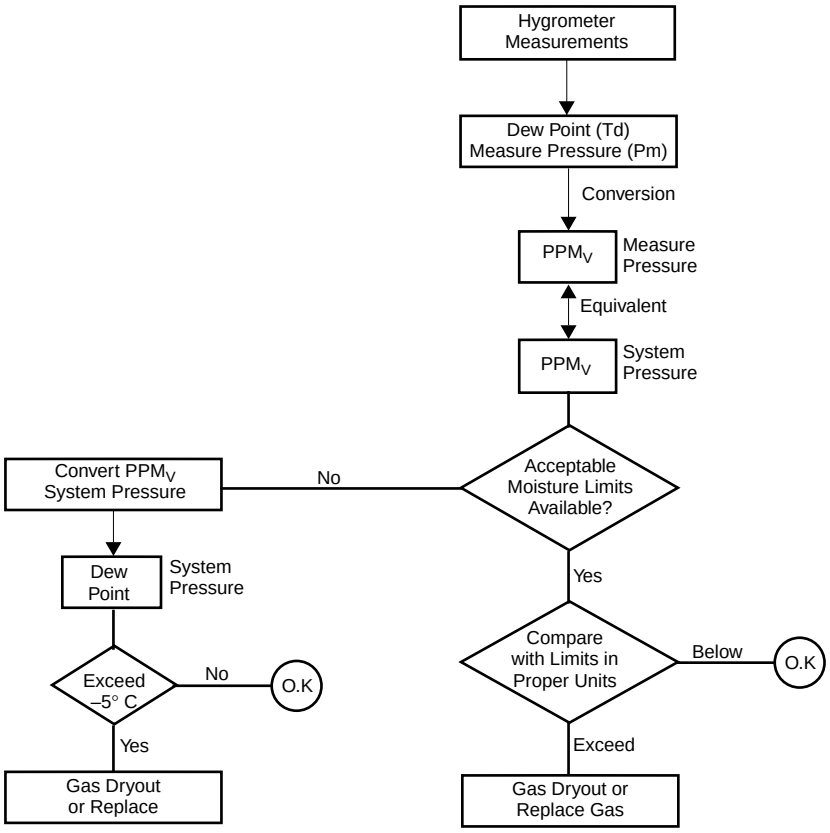


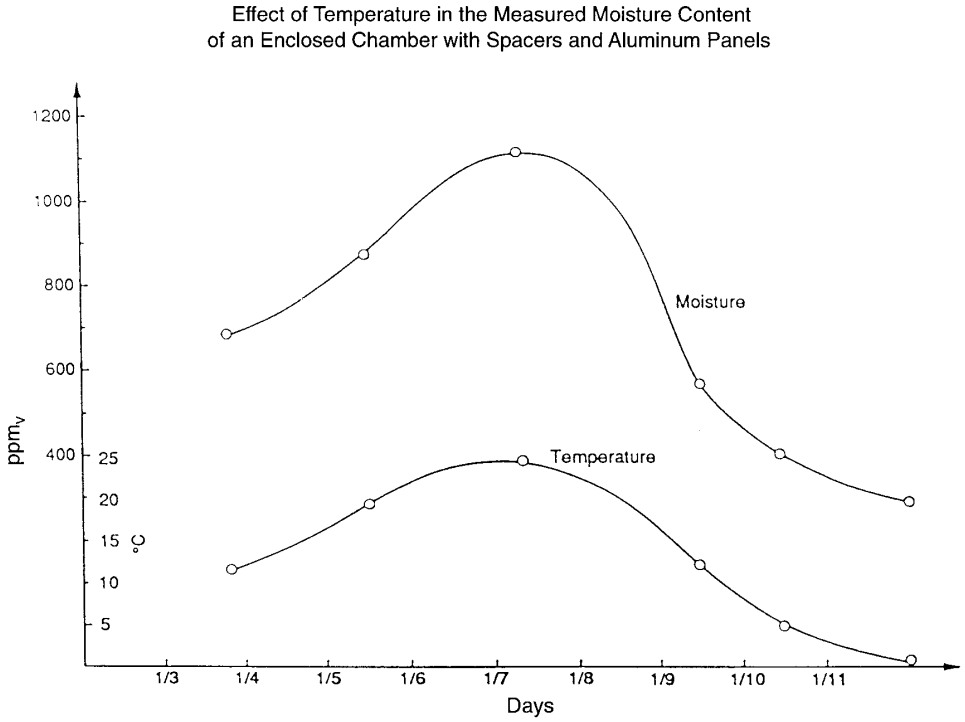
Figure 2—Flow chart for moisture determination and comparison with guidelines

7.2 Temperature effects

The temperature of the system also affects the moisture content in the gas. Moisture is adsorbed on all solid surfaces in the system or absorbed in the solid insulator material. An equilibrium exists between this adsorbed/absorbed moisture and the moisture present in the gas. As the system gets warmer, more moisture is driven from the solid surfaces into the SF_6. Conversely, as the system gets colder, moisture is adsorbed on the walls or on other cold surfaces. Thus, SF_6 systems have a higher moisture content at the higher system temperatures. Therefore, seasonal variations of moisture measurements are usually observed in GIE. A typical experience with the variation of moisture content with temperature is shown in figure 3.

The moisture measurement techniques discussed here determine only the moisture content in the gas. Therefore, the results reflect only a fraction of the total moisture in the system. When moisture measurements are taken in winter, the values are always low in comparison with summer values. This seasonal variation of the recorded moisture values, as well as the variability of the measuring instrument, can give the impression of erratic measurements—which can be confusing to maintenance personnel. Without a satisfactory explanation, this variability in the recorded values can eventually lead to loss of confidence in the overall moisture

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NOTE—Results obtained from experiments carried out at the Norwegian Institute of Technology [B4].

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Figure 3—Seasonal variation of moisture content in a typical GIE compartment

measurement program. The effects of temperature on moisture content also imply that moisture measurements should be carried out in the summer months in order to establish the maximum moisture values in the system. This is a common practice among utilities. (The effects of temperature on the distribution of moisture in GIE are discussed extensively in other sources [B9], [B2].)

8. Moisture control

In order to formulate an effective moisture control program, it is necessary to understand the moisture dynamics in GIE. After the major sources and sinks of moisture have been identified, control techniques can be applied to keep the moisture at an acceptable level. Since the GIE compartment is completely enclosed, the major sources of moisture are surface adsorption and bulk absorption (internal), and leaks through cracks and permeation through seals (external).

8.1 Adsorbed and absorbed moisture

Adsorbed moisture is water in molecular form that sticks on the surfaces of the aluminum conductors, enclosures, and epoxy spacers. Surface adsorption is different from surface condensation because water in the

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adsorbed mode is not in the liquid phase. Since most aluminum surfaces contain a thin oxide layer, the amount of moisture adsorbed can be significant.

Absorbed moisture is water in molecular form that permeates into the organic solid, mainly into the filled epoxy spacers in the GIE compartment. When the spacers initially are exposed to humid ambient air, the water molecules permeate into the epoxy. The rate of permeation is proportional to the diffusivity and solubility of the water vapor in the solid.

Although the diffusion rate of water vapor into the epoxy solid is slow, a significant amount of water can be absorbed by the spacer after fabrication, and prior to commissioning, due to the large mass of the spacers. Recent research indicates that adsorbed and absorbed moisture constitutes the biggest source of moisture in GIE [B3]. Further research has shown that an effective way to control moisture is to prevent it from getting into spacers in the first place [B4]. Placing the epoxy spacers in a dry environment can minimize the amount of moisture uptake. As shown in figure 4, absorbent materials also are effective in keeping moisture from entering epoxy spacers. In practical situations, moisture can be controlled through the use of enclosures (such as plastic bags) with absorbents.

Other sources of moisture, such as diffusion through pinhole leaks, permeation through organic material seals, and aluminum porosity, are minor compared with the adsorbed or absorbed moisture on the aluminum enclosures and epoxy spacers.

Because the rate of desorption is proportional to temperature, the combination of heating and applying vacuum to the compartment is an effective drying technique. However, heating a full size GIE compartment is impractical in most circumstances and vacuuming is the only viable technique to remove surface moisture. Moisture scavenging with an extremely dry gas over an extended period of time is required to remove the absorbed moisture from the bulk.

8.2 Effect of vacuuming

Prior to filling the GIE with the SF_6, the GIE compartments usually are evacuated to a pressure prescribed by the manufacturer. Recent research [B4], [B7] has demonstrated that the application of a vacuum is an effective way to remove surface adsorbed moisture. Figure 5 illustrates the differences in the amounts of moisture desorbed from a stack of aluminum panels with large surface areas under vacuumed and non-vacuumed conditions. As this figure shows, the removal of adsorbed moisture can occur at a very rapid pace. When the proper vacuum level is reached, complete desorption can be achieved in a matter of hours.

Previous research indicates that the time constant for the absorbed moisture in the spacer to diffuse is on the order of weeks [B6]. Applying a vacuum for a short time removes only the surface adsorbed moisture, mostly on aluminum surfaces. Thus, a prolonged pumping time, such as 24 h, will not remove the absorbed moisture in the bulk material, such as the epoxy insulators—the vacuum needs to be applied for weeks to achieve this. Purging the GIE compartment with gas, such as dry nitrogen or dry air, may be another alternative for removing the bulk absorbed moisture. After the dry gas has taken up the desorbed moisture, it can be discarded (in the case of air or nitrogen) or dried again by passing it through a dryer (if SF_6 is used). After initially filling the GIE with SF_6, the moisture level in the gas increases slowly, as the water vapor is desorbed from the internal surfaces, until the moisture inside and outside the epoxy materials is in equilibrium. Most manufacturers recommend checking the moisture content six months after filling to ensure that the moisture limit has not exceeded the recommended values as a result of moisture desorption from the solid materials.

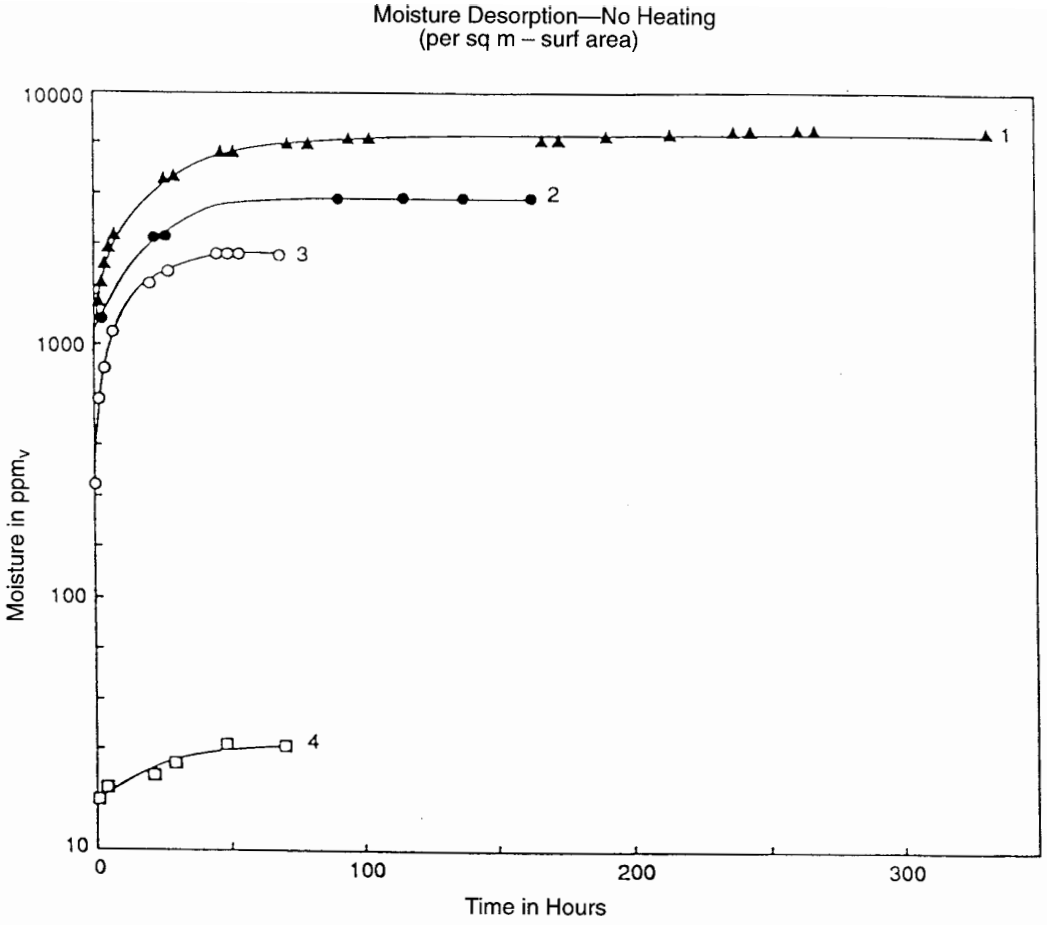
8.3 External moisture sources

The most common sources of moisture ingress from the outside of the GIE enclosure are permeations through rubber seals, gaskets, and pin-hole leaks. The mechanism of moisture ingress is through the process

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of diffusion, driven by the water vapor partial pressure difference between the compartment and the ambient air. Since SF_6 is significantly drier than air, the water vapor partial pressure difference generates a gradient, driving the water through the organic material seals to the SF_6—even though the pressure is higher inside the chamber than outside (i.e., against the gas flow).

In a properly designed and assembled GIE system, the amount of external moisture that diffuses into the GIE through leaks and O-rings has been shown to be small compared to the moisture coming from the epoxy spacers and the adsorbed moisture on the aluminum walls [B4]. However, in order to prevent accumulation of excessive moisture inside the compartment, leaks should be kept to a minimum.



LEGEND
1) Spacer initially conditioned at 100% RH for two months.
2) Spacer initially conditioned at 58% RH for two months.
3) Spacer initially conditioned in enclosure packed with moisture absorbents for 11 days.
4) Aluminum panels initially conditioned at 58% RH for one month.

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Figure 4—Moisture content detected in an enclosed chamber with materials placed inside (as specified in legend)

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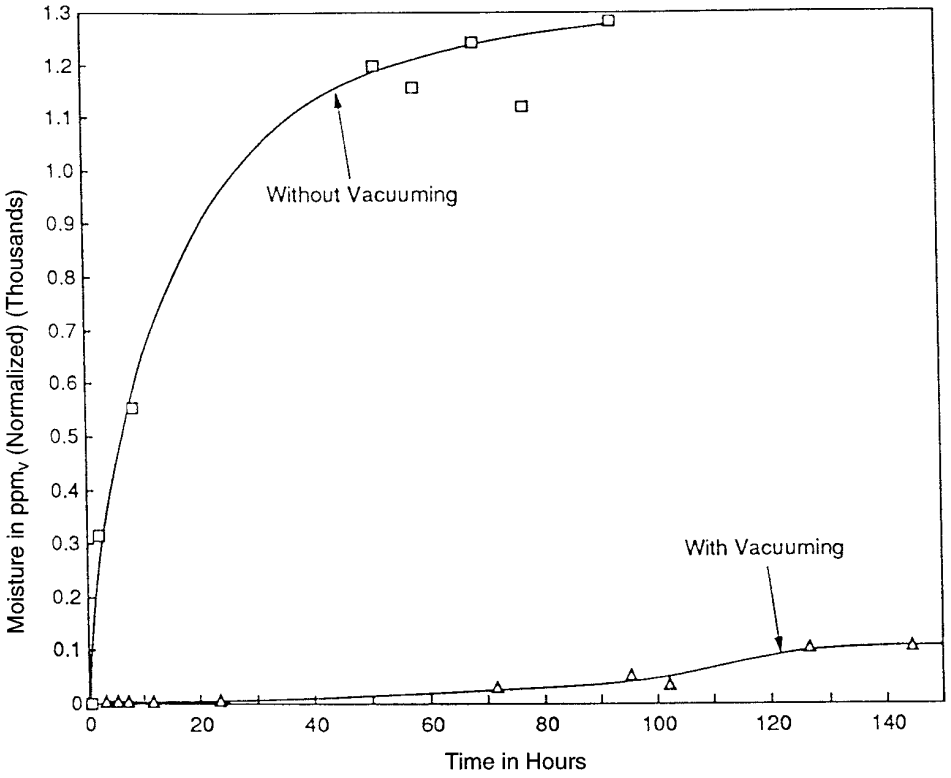


Figure 5—Effects of vacuuming on the moisture content of aluminum surfaces

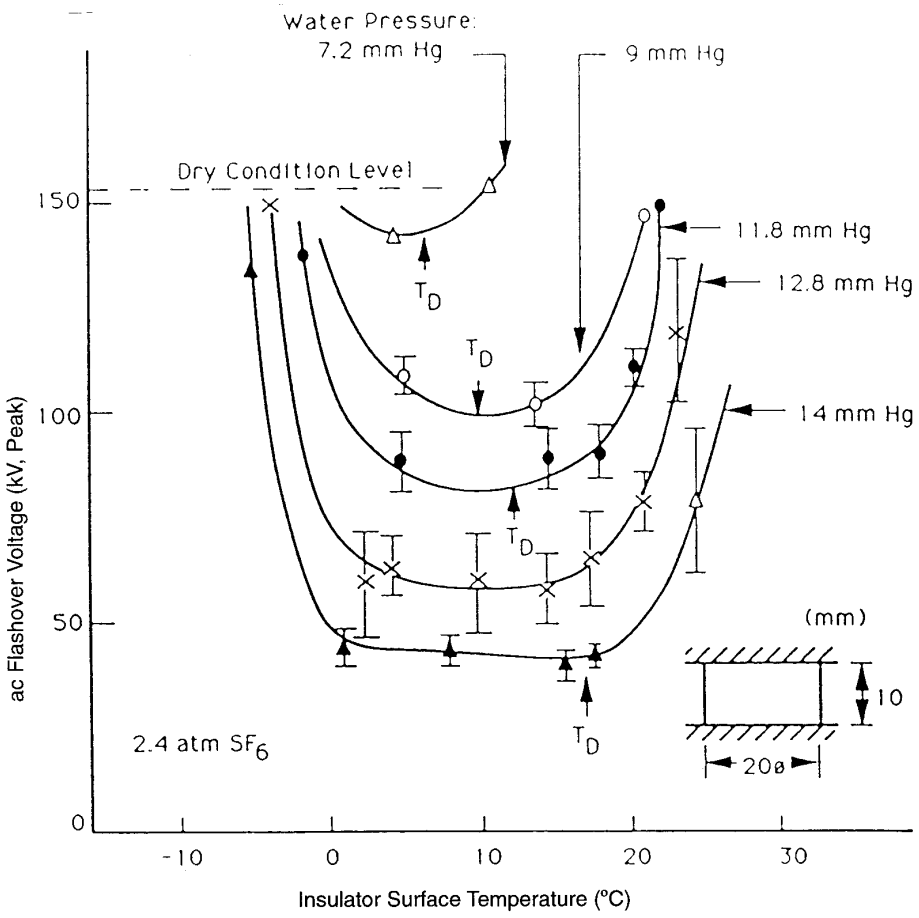
8.4 Application of desiccant

Many manufacturers have installed desiccant canisters in the GIE compartments to absorb any excessive moisture and arc by-products. The absorbent materials effectively remove moisture in the gaseous phase by trapping it on the desiccant's surfaces. With proper handling of the desiccant materials, the moisture levels in the gas compartments (such as circuit breaker chambers) can be maintained at a low level.

In compartments where desiccants are not used, moisture can be removed from the gas by passing the SF_6 through the gas handling system equipped with a desiccant dryer. The dryer materials are normally activated alumina and molecular sieves. The dryer material can be arranged in the gas handling system so that gas withdrawn from the equipment passes through the dryer and into the storage tank. It then can be returned from the tank to the compartment, again passing through the dryer. Care should be exercised to ensure that the desiccant is not saturated before the gas is passed through the dryer system back into the equipment. A closed recirculation system, in which the gas is removed from one end of the chamber and returned to the other end through a dryer while the system is energized, has also been examined [B5]. Experiments have shown that the turbulence generated in the SF_6 at the filling port is not a problem during such recirculation [B4]. The other factors to consider before implementing recirculation of SF_6 on an energized system are the cleanliness of the return hose and the adaption of proper filters to prevent particles from entering the chamber.

Although most desiccant materials can be reactivated after they have been saturated with water vapor, such practice is not recommended in GIE operation. When used in circuit breakers, the desiccant absorbs arc by-products and moisture. Heating of the contaminated desiccant can lead to a catalytic reaction between the

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Figure 6—Influence of moisture on the ac flashover voltage on GIE space surface

desiccant materials and the corrosive by-products. This reaction is known to be exothermic, and can generate sufficient heat to cause equipment damage. Saturated desiccants should be replaced with new material. Reactivation of desiccants, after application in an SF_6 environment known to contain traces of arc by-products, is not recommended.

9. Acceptable moisture limits and moisture check intervals

As indicated in clause 1, the major reason for controlling moisture in GIE compartments is to prevent condensation of moisture on the surface of the solid insulating spacers and the conductor. Previous research [B9], [B2] has shown that the formation of liquid on the spacer surface can reduce the dielectric withstand strength, while the formation of ice on the surface has negligible effects (see figure 6). Therefore, the dew point is used as one of the criteria for determining acceptable moisture limits in GIE. Since moisture can

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combine with trace amounts of arc by-products in the gas to form corrosive hydrofluoric (HF) acid, some equipment manufacturers have established more stringent moisture limits in compartments such as circuit breakers. Table 2 outlines a few acceptable limits recommended by manufacturers, in addition to IEC and ASTM standards for new gases. It should be noted that the IEC and ASTM standards are for new gases to be introduced into the GIE compartment, and that these specifications do not constitute the moisture limits in the equipment. In practice, the moisture level increases after the introduction of new gas into the compartment—the result of moisture redistribution from spacers and aluminum enclosure walls, as discussed in clause 7. The limits suggested by manufacturers in table 2 are equilibrium values taken several months after the new gas is introduced. The manufacturer's recommendations should be followed for acceptable moisture limits and for initial and periodic moisture checks.

Table 2—Recommended moisture limits and specifications from various manufacturers

	Moisture limits (in PPMV)		
	Circuit breakers	**Other equipment**	**Remarks**
GIS manufacturer			
A	400	550	
B	100		Dead tank puffer–1
	400		Dead tank puffer–2
	810		Live tank puffer
		800	Bus
C	120	600	
D	300	300	
E	70		Two pressure type
		150	Bus with disconnect switch
		500	Bus w/o disconnect switch
F	150	1000	
SF_6 gas manufacturer			
A	11*	11*	Typical new gas specifications
Standards			
IEC 376 (1971)* [B8]	120†	120†	New SF_6 gas
ASTM D2472-92* [B1]	71†	71	New SF_6 gas

* Based on liquid phase sampling.
† Reproduced from [B4].

10. Summary

In order to obtain a reliable measure of moisture content in gas-insulated equipment it is necessary to establish consistent procedures specific to the type of moisture measurement instrument to be used. Conversion factors shall be properly applied to the specific instrument readings so they can be properly related to the units of measurements, as specified by the GIE manufacturers for acceptable moisture limits. In addition,

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moisture measurement shall be related to the equipment temperature and pressure. When these factors are under adequate control, the records of the moisture content collected over time show a pattern of consistent measurements. This provides a solid foundation for diagnosing the GIE for moisture problems—and, if necessary, the need for corrective action.

An effective moisture control program also should take into account the various internal and external moisture sources. Moisture adsorption and absorption on epoxy spacers, before commissioning and after repair, constitute the biggest source of moisture in GIE. Proper handling of epoxy spacers and aluminum enclosure surfaces greatly reduces the amount of moisture in GIE. The proper use of desiccants, both inside the GIE enclosure and on the gas handling equipment, is also an effective way to remove moisture. With a carefully formulated moisture control program, the levels of moisture in the GIE can be maintained at an acceptable level, preventing the risk of flashover and corrosion caused by the condensation of water.

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[B8] IEC 376 (1971), Specification and Acceptance of New Sulphur Hexafluoride.[3]

[B9] Nitta, T. et al., "Factors controlling surface flashovers in GIS," *IEEE Transactions on Power Apparatus and Systems*, vol. PAS-97, no. 3, pp. 959-965, 1978.

[2]ASTM publications are available from the Customer Service Department, American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103, USA.

[3]IEC publications are available from IEC Sales Department, Case Postale 131, 3, rue de Varembé, CH-1211, Genève 20, Switzerland/Suisse. IEC publications are also available in the United States from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

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