

ANSI/IEEE Std 4-1978

IEEE STANDARD TECHNIQUES FOR HIGH VOLTAGE TESTING

**IEEE Standard Techniques
for High-Voltage Testing
Sixth Edition**

IEEE Std 4-1978 establishes standard methods of measurement of high-voltage and basic testing techniques for application to all types of apparatus for alternating voltages, direct voltages, lightning impulse voltages, switching impulse voltages, and impulse currents. It is a new, greatly enlarged revision of IEEE Std 4-1968, Techniques for Dielectric Tests.

Section 1 is devoted to the definition of terms for general applications, and the presentation of general requirements regarding test objects and test procedures. Section 2 defines terms relating to the specific tests and describes methods for generation and measurement of test voltages and currents, for testing, and for the evaluation of test results. Applicable to devices and to complete systems used for the measurement of voltages and currents during dielectric testing, Section 3 provides definitions of terms related to measurements, states the requirements which the measuring systems shall meet, and describes some of the devices used. Section 4, an application guide for measuring devices, provides information on measuring systems and devices used for the measurement of high-voltage or currents during the performance of dielectric tests, and describes measuring and calibration procedures. Section 5 addresses the use of the sphere gap for the measurement of peak value and describes the geometry of the standard sphere gap, defines its connections, outlines its use, and provides sphere gap disruptive-discharge voltage data, including the influence of atmospheric data, the sources of these data, and the tolerances or the accuracy.

This Sixth Edition has changed the standard reference temperature from 25°C to 20°C to agree with IEC practice, and includes specifications for wet tests and switching impulse tests, a revised wet test procedure, contamination testing procedures, and an application guide for measuring devices.

SH06965

An American National Standard
**IEEE Standard Techniques for
High-Voltage Testing**



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ANSI/IEEE
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(Revision of
IEEE Std 4-1969)

An American National Standard
**IEEE Standard Techniques for
High-Voltage Testing**

6th Edition

Sponsor

Power System Instrumentation and Measurements Committee
of the
IEEE Power Engineering Society

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Foreword

(This Foreword is not a part of IEEE Std 4-1978, Standard Techniques for High-Voltage Testing.)

This standard establishes standard methods of measurement of high voltage and basic testing techniques so far as they are generally applicable to all types of apparatus for alternating voltages, direct voltages, lightning impulse voltages, switching impulse voltages, and impulse currents.

This standard consists of the following sections:

- Section 1: General Definitions and Test Requirements
- Section 2: Test Procedures
- Section 3: Measuring Devices
- Section 4: Measuring Devices Application Guide
- Section 5: Voltage Measurements by Means of Sphere Gaps

These sections are based on and adhere very closely to the following IEC High-Voltage Test Techniques documents.

- IEC Publication 60-1(1973) — General Definitions and Test Requirements
- IEC Publication 60-2(1973) — Test Procedures
- IEC Publication 60-3(1976) — Measuring Devices
- IEC Publication 60-4(1977) — Measuring Devices Application Guide
- IEC Publication 52(1960) — Recommendations for Voltage Measurement by Means of Sphere Gaps

The current revision of IEEE Std 4 is the sixth edition of this document as a separate standard. The subject had been addressed in the earliest Standardization Report of the American Institute of Electrical Engineers (AIEE) in 1899 and had been substantially elaborated upon in the subsequent reports issued from 1902 to 1933. When it was decided, in 1922, to reorganize the Institute's standards into separate sections, measurement of test voltages became one of the first subjects to be designated for separate publication. The first edition was published in 1928.

In 1956, at the meeting of Technical Committee No 42 of the International Electrotechnical Commission (IEC) in Munich, it was agreed that new sphere gap tables should be prepared which could be accepted internationally. The new tables were to be the mean of the values accepted by the IEC in July 1939 and the values in AIEE No 4-1953 (after adjustment for temperature). The revision of AIEE No 4-1953, IEEE Std 4-1969, reflected those new values and was based upon IEC Publication 52(1960).

In this current revision of IEEE Std 4, the standard reference temperature has been changed from 25°C to 20°C to agree with IEC practice. As a result the sphere gap values are now the same as those in IEC Publication 52(1960).

Included in this document are specifications for wet tests and switching impulse tests which supersede AIEE No 29-1941 and IEEE Std 332-1972 (ANSI C68.2-1972) respectively. Also included are a revised wet test procedure, contamination testing procedures, and an application guide for measuring devices.

When it approved this standard, the High-Voltage Testing Techniques Subcommittee of the Power Systems Instrumentation and Measurements Committee had the following membership:

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In order to resolve negative votes within American National Standards Committee C68 on High Voltage Testing Techniques, that committee proposed the addition of Appendix 2B on measurements with rod gaps. The proposal met with concurrence by the High-Voltage Testing Techniques Subcommittee of the Power Systems Instrumentation and Measurements Committee since the appendixes are not requirements of the standard, and reference within the body of the standard make it clear that the rod gap test does not meet the accuracy requirements of this standard.

At the time American National Standards Committee C68 approved this standard, it had the following membership:

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Contents

Section 1: General Definitions and Test Requirements

SECTION	PAGE
1.1 General	13
1.1.1 Scope and Object	13
1.2 General Definitions	13
1.2.1 Impulses	13
1.2.2 Characteristics Related to Disruptive Discharge and Test Voltages	13
1.2.3 Classification of Insulation	15
1.3 General Requirements Relating to Test Procedure and Test Objects	15
1.3.1 General Arrangement of the Test Object	15
1.3.2 Dry Tests	15
1.3.3 Wet Tests	15
1.3.4 Artificial Contamination Tests	20
1.3.5 Atmospheric Conditions	22
FIGURES	
Fig 1.1 (a) Nozzle Type I. (b) Nozzle Type II. (c) Nozzle Type III (Details of Orifice Only). (d) Nozzle Type IV (For American Practice)	17–19
Fig 1.2 Temperature Correction Factor for Resistivity of Sodium Chloride (NaCl) in Water as Used in Wet Tests and Tests Under Artificial Contamination	20
Fig 1.3 Humidity Correction Factor k as a Function of Absolute Humidity	24
Fig 1.4 Values of the Exponents m and n for Air Density Correction and w for Humidity Correction, as a Function of Sparkover Distance, in meters	24
Fig 1.5 Absolute Humidity of Air as a Function of Dry- and Wet-Bulb Thermometer Readings	26
TABLES	
Table 1.1 Precipitation Conditions (Revised Test Procedure)	16
Table 1.2 Precipitation Conditions (Conventional Procedures) for Wet Tests with Alternating Voltage	19
Table 1.3 Application of Atmospheric Correction Factors	25
APPENDIXES	
Appendix 1A Details of the Pre-Deposited Contamination Method	27
Appendix 1B Production of Saline Fog	31
Appendix 1C Measurement of the Degree of Contamination	35
APPENDIXES FIGURES	
Fig 1A.1 Example of Fog Nozzle	29

APPENDIXES FIGURES	PAGE
Fig 1B.1 Resistivity of Solution of Sodium Chloride (NaCl) in Water, as a Function of Salinity at Solution Temperature t 10°C, 20°C, and 30°C.	31
Fig 1B.2 Density of Solution of Sodium Chloride (NaCl) in Water, as a Function of Salinity at Solution Temperature t of 10°C, 20°C, and 30°C.	32
Fig 1B.3 Saline Fog Jet; See Appendix 1B.	33
APPENDIXES TABLES	
Table 1A.1 Preferred Resistivities	28

Section 2: Test Procedures

SECTION	
2.1 General	37
2.1.1 Scope and Object	37
2.2 Test with Direct Voltage	37
2.2.1 Definitions of Direct-Voltage Tests	37
2.2.2 Test Voltage	37
2.2.3 Test Procedures.	39
2.3 Test with Alternating Voltage	39
2.3.1 Definitions for Alternating-Voltage Tests	39
2.3.2 Test Voltage	40
2.3.3 Test Procedures.	42
2.4 Test with Lightning-Impulse Voltages	42
2.4.1 Definitions for Lightning-Impulse Tests	42
2.4.2 Test Voltage	47
2.4.3 Test Procedures.	49
2.5 Tests with Switching-Impulse Voltages	51
2.5.1 Definitions for Switching-Impulse Tests	51
2.5.2 Test Voltage	52
2.5.3 Test Procedures.	53
2.6 Tests with Impulse Currents	54
2.6.1 Definitions for Impulse-Current Tests	54
2.6.2 Test Current	54
2.7 Bibliography	55
2.7.1 Class 1 Tests	55
2.7.2 Class 2 Tests	55
2.7.3 Class 3 Tests	56
FIGURES	
Fig 2.1 Examples of Lightning Impulses with Oscillations or Overshoot	43
Fig 2.2 Full Lightning Impulse	44

FIGURES	PAGE
Fig 2.3 Lightning Impulse Chopped on the Front	44
Fig 2.4 Lightning Impulse Chopped on the Tail	46
Fig 2.5 Linearly Rising Front-Chopped Impulse	46
Fig 2.6 Voltage/Time Curve for Impulses of Constant Prospective Shape	48
Fig 2.7 Full Switching Impulse	51
Fig 2.8 Circuit for Generation of Switching Impulses Using a Transformer. . .	53

TABLES	PAGE
Table 2.1 Power Supply Requirements	41

APPENDIXES	PAGE
Appendix 2A Statistical Evaluation of Test Results	57
Appendix 2B Rod Gap	61

APPENDIX TABLES	PAGE
Table 2A.1 Factors for Determination of 95% Confidence Limits.	59
Table 2B.1 Rod-Gap Sparkover Crest Voltages	61

Section 3: Measuring Devices

SECTION	PAGE
3.1 General	62
3.1.1 Scope and Object	62
3.1.2 General Principles	62
3.1.3 Definition of General Terms Related to Measurements	63
3.1.4 General Requirements on Measuring Systems	63
3.2 Measuring Systems for Direct Voltages	66
3.2.1 Quantities to be Measured, Accuracies Required, and Requirements of the Measuring System	66
3.3 Measuring Systems for Alternating Voltages	66
3.3.1 Quantities to be Measured, Accuracies Required, and Requirements of the Measuring System	66
3.4 Measuring Systems for Impulse Voltages.	67
3.4.1 Quantities to be Measured and Accuracies Required	67
3.4.2 Classification of Impulse Measuring Systems.	67
3.4.3 Requirements of Measuring Systems	68
3.4.4 Maximum Frequency to be Recorded, $f_{\max}$	69
3.5 Measuring Systems for Impulse Currents.	70
3.5.1 Quantities to be Measured, Accuracies Required, and Requirements of the Measuring System	70

TABLES	PAGE
Table 3.1 Response Time Requirements	69

Section 4: Measuring Devices Application Guide

4.1 General	71
4.1.1 Scope and Object	71

SECTION	PAGE
4.2 Measurement of Direct Voltages	71
4.2.1 General	71
4.2.2 Systems for Measuring the Steady-State Value of Direct Voltages.	71
4.2.3 Systems for Measuring Ripple Voltage	72
4.2.4 Determination of Voltage Ratios and Scale Factors	72
4.2.5 Possible Sources of Errors and Precautions	73
4.3 Measurement of Alternating Voltages	73
4.3.1 General	73
4.3.2 Systems for Measuring the Amplitude of Alternating Voltages	73
4.3.3 Systems for Measuring the Amplitude of Harmonics.	74
4.3.4 Determination of Voltage Ratios and Scale Factors	74
4.3.5 Determination of the Amplitude Frequency Response of a Measuring System	75
4.3.6 Possible Sources of Errors and Precautions	75
4.4 Measurement of Impulse Voltages.	75
4.4.1 General	75
4.4.2 Measuring System Components.	76
4.4.3 Determination of Voltage Ratios and Scale Factors	79
4.4.4 Response of a Measuring System.	80
4.4.5 Procedure for Measuring the Experimental Unit Step Response	80
4.4.6 Determination of the Response Parameters from Experimental Unit Step Response Oscillograms	83
4.4.7 Determination of the Response Parameters by the Sphere-Gap Method	85
4.4.8 Relation of Response Parameters to Measuring Errors.	88
4.4.9 Criteria Relating to Corrections.	90
4.4.10 Evaluation of a Measuring System by Comparison Method	93
4.4.11 Various Sources of Errors, Precautions	93
4.5 Measurement of Impulse Currents.	98
4.5.1 General	98
4.5.2 Commonly Used Measuring Systems	98
4.5.3 Precautions	100
FIGURES	
Fig 4.1 The Unit Step Method.	76
Fig 4.2 Methods of Matching Coaxial Cables.	79
Fig 4.3 Typical Oscillograms Obtained by the Step Method	82
Fig 4.4 Sphere-Gap Sparkover Voltage as a Function of Rate-of-Rise of Voltage (Valid for Negative Voltages).	85
Fig 4.5 Determination of Rate-of-Rise When Using Sphere-Gap Method.	86
Fig 4.6 Response Time and Measurement Errors in Practical Measurements	89
Fig 4.7 Effect of Initial Distortion on Front-Chopped Impulse.	91
Fig 4.8 Determination of $T'\alpha$ for a Response with Steep Initial Portion	92
Fig 4.9 Flow Diagram for Evaluating Impulse Oscillograms (Nonoscillatory Step Response)	94

FIGURES	PAGE
Fig 4.10 Flow Diagram for Evaluating Impulse Oscillograms (Oscillatory Step Response)	95
Fig 4.11 Check of the Proximity Effects.	96
Fig 4.12 Tubular Shunts for Impulse Current Measurements.	99
Fig 4.13 Determination of Step Response of Impulse Current Measuring System	100
TABLES	
Table 4.1 Response Parameters.	81
APPENDIXES	
Appendix 4A Resistor Dividers	101
Appendix 4B Mathematical Basis for Response Time T	103
Appendix 4C Procedure to Determine if Oscillations are Present Across the Test Object	105

Section 5: Voltage Measurements by Means of Sphere Gaps

5.1 General	107
5.1.1 Scope and Object	107
5.2. Standard Sphere Gap.	107
5.2.1 Definition	107
5.2.2 Requirements for the Spheres	107
5.2.3 Construction of the Shanks of the Spheres	109
5.2.4 Height of Spheres Above the Horizontal Ground Plane.	109
5.2.5 Clearance Around the Spheres.	111
5.2.6 Clearance Around the Spheres (Table)	111
5.3 Connection of the Sphere Gap	111
5.3.1 Grounding.	111
5.3.2 High-Voltage Conductor	111
5.3.3 Protective Series Resistance in Measurements of Alternating and Direct Voltage.	112
5.3.4 Protective Series Resistance in Measurement of Impulse Voltages.	112
5.4 The Use of Sphere Gap	112
5.4.1 Irradiation.	112
5.4.2 Voltage Measurements.	113
5.5 Sphere-Gap Disruptive-Discharge Voltages	113
5.5.1 Numerical Values in Table 5.1 and 5.2	113
5.5.2 Accuracy in Tables 5.1 and 5.2	114
5.5.3 Influence of Atmospheric Conditions	114

FIGURES		PAGE
Fig 5.1	Vertical Sphere Gap	108
Fig 5.2	Horizontal Sphere Gap	110
TABLES		
Table 5.1	Sphere Gap With One Sphere Grounded	114
Table 5.2	Sphere Gap With One Sphere Grounded	116
APPENDIXES		
Appendix 5A	Range of Experimental Calibrations	119
Appendix 5B	Procedure by which the Values in Tables 5.1 and 5.2 have been Derived from National Standards and other Sources	121
Appendix 5C	Bibliography	123

Section 1: General Definitions and Test Requirements

1.1 General

1.1.1 Scope and Object. This standard is applicable to: (1) dielectric tests with direct voltage; (2) dielectric tests with alternating voltage; (3) dielectric tests with lightning and switching impulse voltages; (4) tests with impulse current.

The objectives of this standard are: (1) to define terms of general applicability; (2) to present general requirements regarding test objects and test procedures.

1.2 General Definitions

1.2.1 Impulses. An impulse is an intentionally applied aperiodic transient voltage or current which usually rises rapidly to a peak value and then falls more slowly to zero. Such an impulse is in general well represented by the sum of two exponentials.

For special purposes, impulses having approximately linearly rising fronts or of oscillating or approximately rectangular form are used.

The term “impulse” is to be distinguished from the term “surge” which refers to transients occurring in electrical equipment or networks in service.

1.2.1.1 Lightning and Switching Impulses. A distinction is made between lightning impulses and switching impulses on the basis of the duration of the front. Impulses with front durations from less than one up to a few tens of a microsecond are, in general, considered as lightning impulses and those having front durations of some tens up to thousands of microseconds as switching impulses. Generally, switching impulses are also characterized by considerably longer total durations than those of lightning impulses.

NOTE: If required, a more rigorous distinction may be made in an apparatus standard. Such a distinction is made in IEEE Std 28-1974 (ANSI C62.1-1975), Surge Arresters for Alternating-Current Power Circuits, and is based on a virtual front time of 30 μ s.

1.2.2 Characteristics Related to Disruptive Discharge and Test Voltages.

1.2.2.1 Disruptive Discharge. In this standard, the term “disruptive discharge” relates to phenomena associated with the failure of insulation under electrical stress, in which the discharge completely bridges the insulation under test, reducing the voltage between the electrodes to zero or nearly to zero. It applies to electrical breakdown in solid,

liquid, and gaseous dielectrics and to combinations of these.

Discharges between intermediate electrodes or conductors, as well as momentary flashovers (snap-overs), may occur with alternating voltage without permanent reduction of the test voltage to zero. The occurrence of snap-overs may depend on the characteristics of the test circuit. Whether such an occurrence constitutes a failure or not, and whether it requires a repetition of the test, should be established by the appropriate apparatus standard.

Discharges which do not completely bridge the insulation between electrodes are termed "partial discharges" and are dealt with in ANSI/IEEE Std 454-1973, Recommended Practice for the Detection and Measurement of Partial Discharges (Corona) During Dielectric Tests.

The term "sparkover" is used when a disruptive discharge occurs in a gaseous or liquid dielectric.

The term "flashover" is used when a disruptive discharge occurs over the surface of a solid dielectric in a gaseous or liquid medium.

The term "puncture" is used when a disruptive discharge occurs through a solid dielectric.

A disruptive discharge in a solid dielectric produces permanent loss of dielectric strength; in a liquid or gaseous dielectric, the loss may be only temporary.

1.2.2.2 Value of Test Voltage. The value of the test voltage is the voltage value, defined according to Section 2 of this standard, which is to be applied in a test.

1.2.2.3 Disruptive Discharge Voltage. For direct voltage, alternating voltage, and impulse voltages chopped at or after the crest, the disruptive discharge voltage is the value of the test voltage causing

disruptive discharge. For definition of this value, see Section 2.

For impulse voltages chopped on the front, the disruptive discharge voltage is defined as the voltage at the instant when disruptive discharge occurs (see also 1.2.2.4).

Disruptive discharge voltages are subject to random variations and, usually, a number of observations must be made in order to obtain a statistically significant value of the voltage. The test procedures, described in Section 2, are generally based on statistical considerations. The same document also gives information on the statistical evaluation of test results.

1.2.2.4 Prospective Characteristics of a Test Voltage. The prospective characteristics of a test voltage causing disruptive discharge are the characteristics which would have been obtained if no disruptive discharge had occurred. When a prospective characteristic is referred to, this should always be stated.

1.2.2.5 Disruptive Discharge Probability p . The disruptive discharge probability is the probability that the application of a certain prospective voltage value of a given shape will cause disruptive discharge.

1.2.2.6 Withstand Probability. The withstand probability is the probability that the test object will withstand one application of a certain prospective voltage value and shape. If the disruptive discharge probability is p , the withstand probability is $(1 - p)$.

1.2.2.7 Withstand Voltage. The withstand voltage is the voltage that electrical equipment is capable of withstanding without failure or disruptive discharge when tested under specified conditions.

1.2.2.8 Assured Disruptive Discharge Voltage. The assured disruptive discharge voltage is a specified voltage value which characterizes the insulation of an object

with regard to a disruptive discharge test.

1.2.2.9 50 Percent Disruptive Discharge Voltage. The 50 percent disruptive discharge voltage is the prospective voltage value which has a 50 percent probability of producing a disruptive discharge.

1.2.2.10 x Percent Disruptive Discharge Voltage. The x percent disruptive discharge voltage is the prospective voltage value which has x percent probability of producing a disruptive discharge.

1.2.3 Classification of Insulation.

1.2.3.1 External Insulation. External insulation is the air insulation and the exposed surfaces of solid insulation of equipment, which are subject both to dielectric stresses and to the effects of atmospheric and other external conditions such as contamination, humidity, vermin, etc.

1.2.3.2 Internal Insulation. Internal insulation comprises the internal solid, liquid, or gaseous elements of the insulation of equipment, which are protected from the effects of atmospheric and other external conditions such as contamination, humidity, vermin, etc.

1.2.3.3 Self-Restoring Insulation. Self-restoring insulation is insulation which completely recovers its insulating properties after a disruptive discharge caused by the application of a test voltage. In insulation of this kind, disruptive discharges frequently, but not necessarily, occur in the external part of the insulation.

1.2.3.4 Non-Self-Restoring Insulation. Non-self-restoring insulation is insulation which loses its insulating properties, or does not recover them completely, after a disruptive discharge caused by the application of a test voltage. In insulation of this kind, disruptive discharges generally, but not necessarily, occur in the internal part of the insulation.

1.3 General Requirements Relating to Test Procedure and Test Objects

1.3.1 General Arrangement of the Test Object. At the time of a test, the test object shall be complete in all essential details, and it should have been processed in the normal manner for similar equipment (for instance by vacuum impregnation and thermal treatment).

The disruptive discharge characteristics of a test object may be affected by its general arrangement, for example by its clearance from nearby structures, its height above ground level, the arrangement of the high voltage lead. A clearance to nearby structures equal to 1.5 times the length of the shortest possible discharge path on the test object usually makes such proximity effects insignificant. Larger clearances may be required in the cases of switching impulse tests or in tests at very high voltage, to avoid sparkovers to extraneous structures. In wet tests or contamination tests, or wherever the voltage distribution in the test object is sufficiently independent of external influences, smaller clearances may be acceptable provided that flashovers do not occur to extraneous structures.

1.3.2 Dry Tests. The test object should be dry and clean. If not otherwise specified by the appropriate apparatus standard, the test should be made at ambient temperature and the procedure for voltage application should be as specified in Section 2.

1.3.3 Wet Tests. The wet test method, described in 1.3.3.1 is intended to simulate the effect of natural rain on external insulation and is a revision of earlier test methods. It is recommended for tests with all types of test voltages, and on all

types of apparatus designed for outdoor use.

Two earlier test methods, not intended to simulate natural rain, are described in 1.3.3.2. These have been in use for many years for tests with alternating voltage on apparatus up to about 400 kV system voltage and many test data obtained by these methods exist. Their use is recommended only when direct comparison with such data is required.

1.3.3.1 Revised Wet Test Procedure. The test object should be sprayed with water of prescribed resistivity, falling on it as droplets and directed so that the vertical and horizontal components of the spray intensity are approximately equal. These intensities are measured with a divided collecting vessel having openings of 100 to 750 cm², one horizontal and one vertical, the vertical opening facing the spray. Another less accurate practice is to measure only the vertical component and to judge by eye that the spray is falling at an angle of approximately 45°.

The collecting vessel should be placed close to the test object, but avoiding the collection of drops or splashes from it. During the measuring period, it should be moved slowly over a sufficient area to average out the effect of non-

uniformities of the spray from individual nozzles.

In the case of test objects with a height exceeding 1 m, such measurements should be made near the top, center, and bottom of the object. A similar procedure should be used for test objects with large horizontal dimensions.

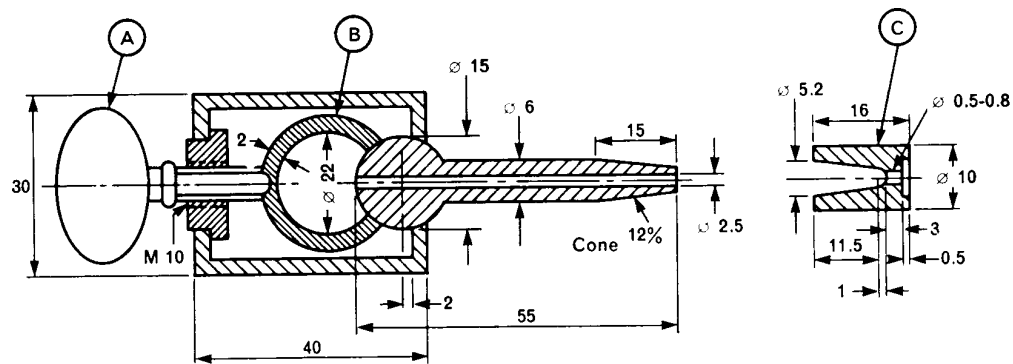
The spray apparatus must be adjusted to produce, within the specified tolerances, precipitation conditions at the test object given in Table 1.1. Any type and arrangement of nozzles meeting the requirements given in Table 1.1 may be used. Examples of several nozzles which have been found satisfactory in practice are shown in Fig 1.1 (a), (b), and (c) together with typical performance data for each type. Greater spray distances may be obtained if the nozzles are directed upward at an angle of about 15°–25° to the horizontal. Note that if the water pressure is increased above the recommended limits, the water jets may break up prematurely and cause an unsatisfactory spray at the test object.

The test object should be prewetted initially for at least 15 min under the conditions specified in Table 1.1 and these conditions should remain within the specified tolerances throughout the test. The prewetting time may include

Table 1.1
Precipitation Conditions (Revised Test Procedure)

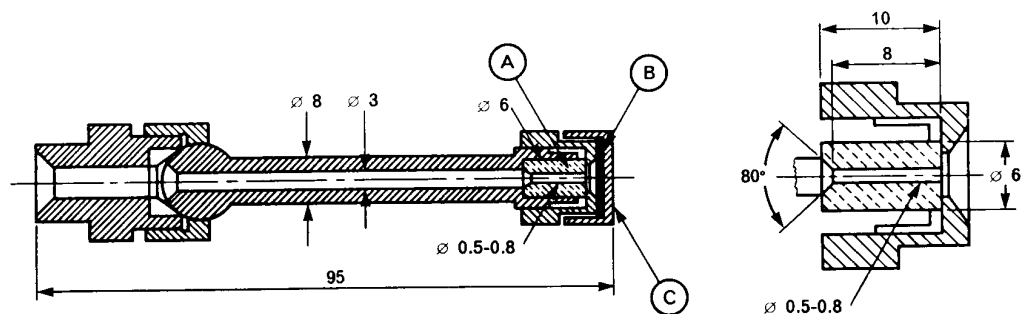
Average precipitation rate for all measurements:		
vertical component	mm/min	1.0 to 1.5
horizontal component	mm/min	1.0 to 1.5
Limits for any individual measurements and for each component	mm/min	0.5 to 2.0
Temperature of collected water	°C	ambient temperature ± 15
Resistivity of collected water corrected to 20°C (see note below)	Ω m	100 ± 15
(For correction of water resistivity to 20°C, see Fig 1.2)		

NOTE: For switching impulses, if the prescribed water resistivity cannot be obtained, a lower value may be used but the actual value must be stated in the test report.



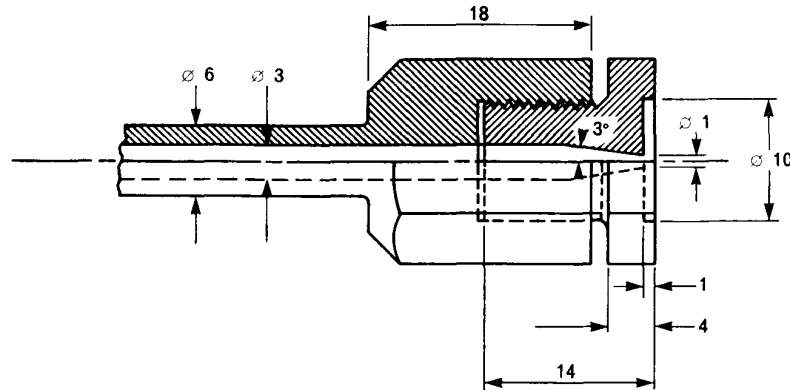
A — nozzle clamping screw, B — water supply pipe,
C — replaceable orifice.

Fig 1.1 (a)
Nozzle Type I.



A — plastic orifice to reduce the risk of obstruction by dirt,
B — rubber seal, C — cover to block water.

Fig 1.1 (b)
Nozzle Type II.



NOTE: The length of water jet which can be obtained depends on the diameter of the orifice and on the water pressure. At the optimum pressure, which usually is $3 \times 10^5 - 4 \times 10^5$ Pa (3–4 atm) but depends on the smoothness of the orifice and the arrangement of the supply pipes, the approximate jet lengths obtainable with the nozzles shown in Fig 1.1 (a) to (c) are given in the following table:

Type of Nozzle	Orifice Diameter (mm)	Length of Water Jet (m)
I and II	0.5	4
	0.8	6
	1.0	10
III	1.0	9–11

Fig 1.1 (c)

(c) Nozzle Type III (Details of Orifice Only).

the time needed for adjustment of the spray and may be reduced if special means are used to ensure effective wetting or when repeat tests are made after short intervals.

Unless otherwise specified by the appropriate apparatus standard, the test procedure for wet tests should be the same as that specified in Section 2 for the corresponding dry tests. In general, for all alternating and direct voltage wet withstand tests, it is recommended that one flashover should be permitted provided that in a repeat test no further flashover occurs.

1.3.3.2 Conventional Procedures for Wet Tests with Alternating Voltage. For alternating voltage tests, two other procedures are also in use, details of which are given in Table 1.2. They differ from the revised procedure, 1.3.3.1, primarily in that the precipitation rates are higher and that the minimum prewetting time is only 1 min.

Only the vertical component of the spray is specified; determination of the horizontal component is replaced by a visual estimate of the spray angle at the test object which should be approximately 45° .

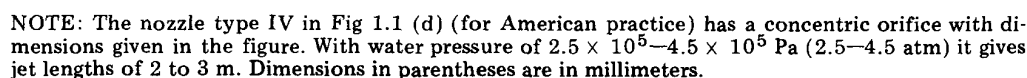


Table 1.2
Precipitation Conditions (Conventional Procedures)
for Wet Tests with Alternating Voltage

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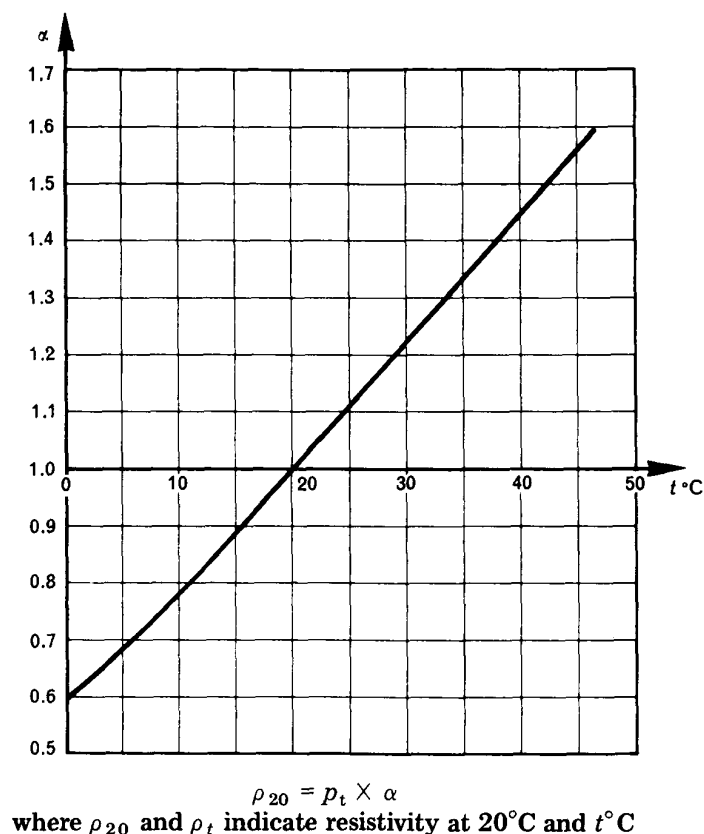


Fig 1.2
Temperature Correction Factor (d) for Resistivity of Sodium Chloride (NaCl)
in Water as Used in Wet Tests and Tests Under Artificial Contamination

1.3.4 Artificial Contamination Tests. Artificial contamination tests are intended to provide information on the behavior of external insulation under conditions representative of contamination in service, although they do not necessarily simulate any particular service conditions.

The following specifications give some general guidance on artificial contamination testing. It is left to the appropriate apparatus standards to introduce varia-

tions or to give more specific requirements for particular classes of apparatus.

The effects of washing of insulators in service by natural rain is not taken into consideration in any of the specified procedures.

1.3.4.1 Preparation of Test Object. Before testing for the first time, the metal parts of the test object, and any cement joints, may be painted with salt-water resistant paint to ensure that corrosion products will not contaminate the in-

sulation surfaces during a test.

The test object should then be carefully cleaned by washing with tap water to which a neutral detergent such as trisodium phosphate (Na_3PO_3) has been added and rinsed with clean tap water. It shall not subsequently be touched by hand. Usually the insulating surfaces can be considered sufficiently clean and free of grease or other contaminating material if large continuous wet areas are observed during wetting.

It is left to the appropriate apparatus standard to specify whether the test object should be tested in a vertical, horizontal, or inclined position.

1.3.4.2 Test Procedures. Artificial contamination tests involve application of contamination and the simultaneous or subsequent application of voltage. Generally, only methods in which the test voltage is held constant for at least several minutes are recommended. Other methods in which the voltage is raised gradually to flashover are not proposed for standardization but may be used for special purposes.

The contamination test may be made either to determine the maximum degree of contamination of the test object which allows a given test voltage to be withstood, or to determine the withstand voltage for a specified degree of contamination. For the purpose of comparing the results of several tests, or the performance of several test objects, the former procedure is preferable. Whichever test procedure is adopted, the number of measurements should be sufficient to obtain consistent average values, taking into account the statistical nature of the phenomenon.

Contamination tests fall into two categories, the pre-deposited method and the saline fog method.

1.3.4.2.1 The Pre-Deposited Contamination Method. There are three general test methods: the "flow-on," "close spray," and clean fog. For all three methods, the contamination is first applied in a layer having approximately uniform thickness. It is usually a mixture of water, a nonconducting binding medium, and salt to give a controlled resistivity.

For the flow-on method, after the coating is applied, it is allowed to stabilize for about 5 min until dripping stops. The voltage is then raised to the desired withstand value and held until a flashover occurs or scintillation ceases.

For the close spray method, flashovers, each followed by recoating with the contaminant without removing the previous coating, are made until the leakage current stabilizes. The insulators are then recoated without washing, and the withstand voltage level applied.

For the clean fog method, the contaminating coating is allowed to dry and the test object is then usually placed in a special test chamber. A fog produced by normal tap water and air, or a steam generator, is used to gradually wet the contaminating layer until its surface resistivity reaches a minimum value. The voltage is applied immediately thereafter (but see Note), raised to the specified value, and kept constant until flashover occurs or a withstand is apparent. This may be about 15 min or, in the case where a steam generator is employed, as long as 2 h.

Details of suitable coating and wetting procedures for the pre-deposited method are given in Appendix 1A and procedures for the measurement of the surface resistivity in Appendix 1C.

When the test is intended to determine the maximum degree of contamination for a specified withstand voltage, the coating, wetting, and test procedures

must be repeated using various different suspension resistivities.

The ambient temperature at the start of the test should not be less than 5°C nor greater than 30°C.

NOTE: Pre-deposited contamination methods are also in use in which constant voltage is applied to the test object before the wetting.

1.3.4.2.2 *The Saline Fog Method.*

The test object is placed in a special chamber which can be filled by a saline fog. An example of a method for producing the fog is described in Appendix 1B. The ambient temperature in the chamber at the start of the test should not be less than 5°C, nor greater than 30°C and the test object shall be in thermal equilibrium with the ambient temperature.

The test object is thoroughly wetted with clean tap water. The saline fog system, supplied by water of the prescribed salinity, is started when the test object is still wet and, simultaneously, the voltage is applied to the test object, raised rapidly to the specified value, and kept constant during the specified time, usually 1 h or until flashover occurs. Usually, this procedure is repeated several times. Before each procedure, the test object is thoroughly washed with clean tap water to remove any trace of salt.

If the test is intended to determine the maximum degree of salinity for a specified withstand voltage, the whole procedure must be repeated using various different salinities.

Pre-conditioning of the test object by a number of flashovers during the application of contamination is recommended before the real test begins. Even this pre-conditioning should be followed by a washing.

1.3.4.3 Degree of Contamination. The degree of contamination of a test object

can be specified either by the surface resistivity or by the amount of conductive matter per square centimeter of the insulating surface. Information about these methods is given in Appendix 1C.

1.3.5 Atmospheric Conditions.

1.3.5.1 Atmospheric Correction Factors. The disruptive discharge voltage of external insulation depends upon the prevailing atmospheric conditions. Usually, the flashover voltage for a given path in air is raised by an increase in either air density or humidity. However, when the relative humidity exceeds about 80 percent, the flashover voltage becomes irregular, especially when the flashover occurs across an insulating surface.

By applying correction factors, a measured flashover voltage may be converted to the value which would have been obtained under the reference atmospheric conditions. Conversely, a test voltage specified for the reference conditions can be converted into the equivalent value under the prevailing test conditions.

There are two correction factors:

- (1) The air density correction factor k_d (see 1.3.5.3);
- (2) The humidity correction factor k_h (see 1.3.5.3).

The disruptive discharge voltage is proportional to k_d/k_h .

If not otherwise specified by the appropriate apparatus standard, the voltage to be applied during a withstand test on external insulation is determined by multiplying the specified withstand voltage by k_d/k_h . Similarly, measured disruptive discharge voltages are corrected to those applicable for standard reference atmosphere by dividing by k_d/k_h .

It is left to the appropriate apparatus standard to specify whether or not corrections have to be applied to the voltage values in those cases where both external and internal insulations are in-

$$k_h = (k)^w.$$

The symbols of Table 1.3 are:

NOTE: In Table 1.3 and Figs 1.3 and 1.4, a simplification of the existing information is given. The available experimental data from different sources always show large dispersions and are often conflicting; moreover, rele-

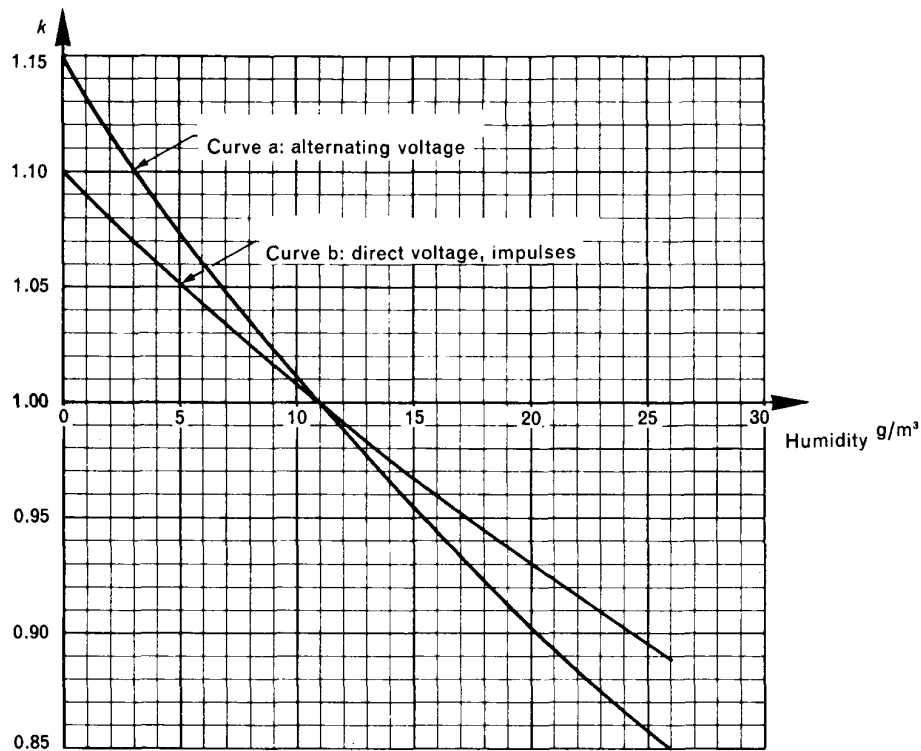


Fig 1.3
Humidity Correction Factor k as a Function of Absolute Humidity.
(For applicability, see 1.3.4.3 and Table 1.3).

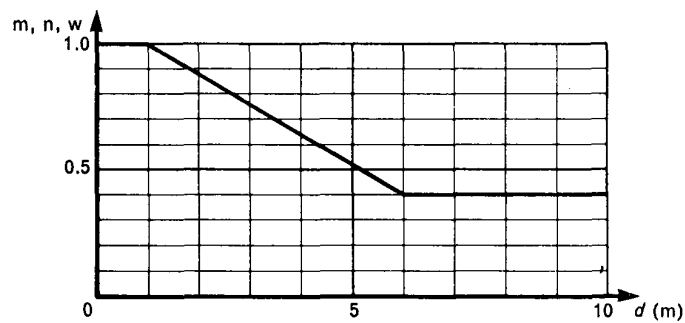


Fig 1.4
Values of the Exponents m and n for Air Density Correction and w for Humidity Corrections, as a Function of Sparkover Distance, in Meters.
(See 1.3.4.3 and Table 1.3.)

Table 1.3
Application of Atmospheric Correction Factors

Type of Test Voltage	Electrode Form	Polarity	Air Density Correction	Humidity Correction	
			Exponents m and n (see note in 1.3.5.3)	Factor k	Exponent w
Direct voltage		+	1.0	see Fig 1.3, (curve b)	0
		-			0
		+			1.0
		-			1.0
		+			1.0
		-			0
Alternating voltage		~	1.0	see Fig 1.3 (curve a)	0
		~	see Fig 1.4		see Fig 1.4
		~	see Fig 1.4		see Fig 1.4
Lightning impulse voltage		+	1.0	see Fig 1.3 (curve b)	0
		-			0
		+			1.0
		-			0.8
		+			1.0
		-			0
Switching impulse voltage		+	1.0	see Fig 1.3 (curve b)	0
		-	1.0		0
		+	see Fig 1.4 0*		see Fig 1.4 0*
		-	see Fig 1.4 0*		see Fig 1.4 0*
		+	see Fig 1.4 0*		see Fig 1.4 0*
		-	see Fig 1.4 0*		see Fig 1.4 0*

*Very little information is available. At present no correction is recommended.

vant information for direct voltages and for switching impulses is scarce. The correctness of using equal exponents m and n , and of their numerical values as given, is therefore uncertain.

1.3.5.4 Measurement of Humidity. The measurement of humidity is usually made by means of a hygrometer consist-

ing of two ventilated accurate thermometers, one being dry, the other wetted. The absolute humidity as a function of the two thermometer readings is determined by Fig 1.5, which also permits a determination of the relative humidity. It is important to provide adequate air

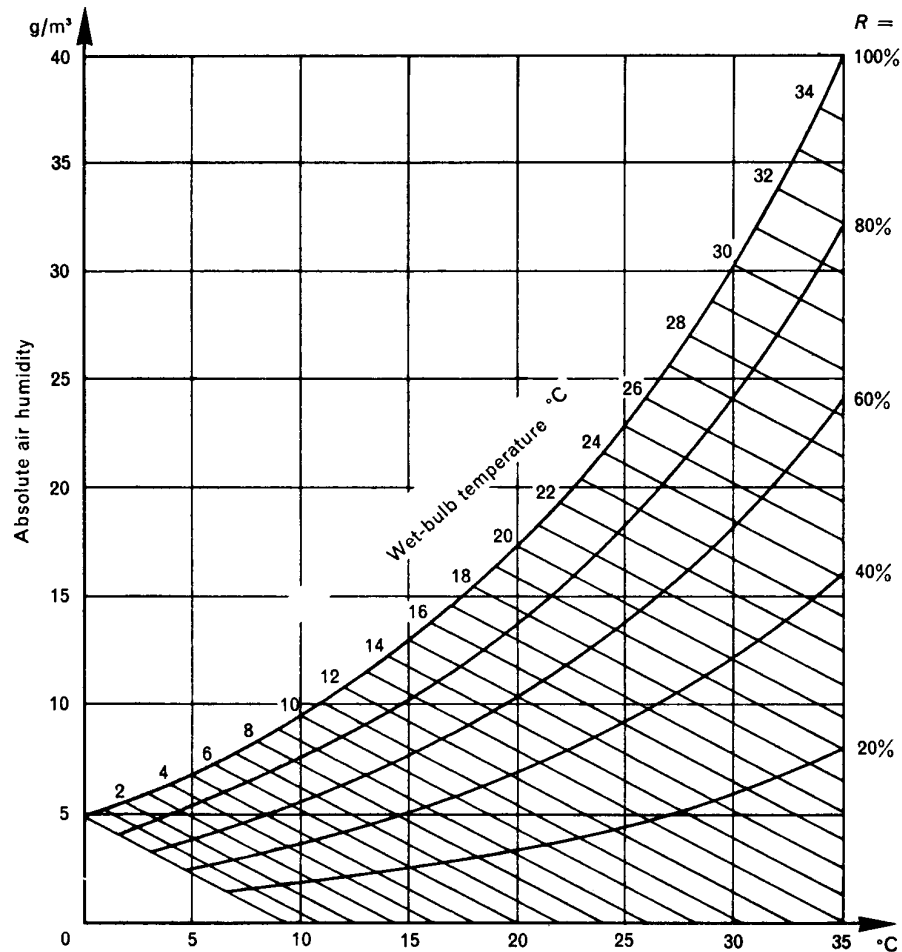


Fig 1.5
Absolute Humidity of Air as a Function of Dry- and Wet-Bulb
Thermometer Readings. (See 1.3.4.4.) Curves of Percentage Relative
Humidity are also Given.

flow (4-10 m/s)¹ to reach steady-state values of the readings and to read the thermometers carefully, in order to

¹Smithsonian *Meteorological Tables*, 6th Revised Edition, Smithsonian Publication 4014, p 365.

avoid excessive errors in the determination of humidity.

Other methods for the determination of the humidity are available and may be used if it can be demonstrated that they give sufficient accuracy.

Appendix 1A

(This Appendix is not a part of IEEE Std 4-1978, IEEE Standard Techniques for High-Voltage Testing, Section 1.)

Details of the Pre-Deposited Contamination Method

1A.1 Flow-On Method. For this type of test method where it is important that the surface maintain a uniform wetness over an extended period of time, the following contaminating slurry is recommended.

- 20 g of pyrogenic silica, particle size $0.007\ \mu\text{m}$ (see Note 1)
- 1 g photographic wetting agent (see Note 2)
- 1000 g tap water
- 1-40 g of NaCl to give the desired resistivity.

Other compositions of the contaminating slurry containing binders of kaolin or bentonite may be used, but it should be demonstrated that they result in approximately the same contamination level as the pyrogenic silica.

To obtain comparable test results, the measured resistivity of the suspension, when corrected to the equivalent value at 20°C (see Fig 1.2), should be within ± 15 percent of one of the values ρ_{20} given in Table 1A.1.

The above solution is flow-coated on to the insulators until the entire surface is covered to the point of run-off. In the case of a small number of insulators this may be accomplished by dipping. For a larger number of insulators or free stand structures such as lightning arresters, it may be advisable to build special apparatus in order to accomplish the flow coating quickly. This can be accomplished by means of small cylindrical tubes, the

ends of which have been pinched to obtain an approximate elliptical cross section with internal dimensions of 3×6 mm. Several of these tubes are regularly spaced on a circular ring and directed inwardly. The contaminating solution is forced through these tubes by a pump of suitable pressure. The ring and the outlets are so designed that the assembly can be passed slowly and progressively over the insulator to be coated, the axis of the insulator being approximately at the center of the ring. The outlets are directed at an angle to obtain a swirling movement of the suspension and so as to provide a complete coating of the insulating surfaces. The coating procedure is carried out until the deposited suspension is to the point of dripping off. Any other coating apparatus may be used that will result in the insulators being completely coated to the point of run-off. When the coating has been completed, a sufficient time (about 5 min) is allowed for any dripping to cease, and for the coating to stabilize. The voltage is then applied and raised rapidly to the specified test level. It is then maintained at this value until a flashover occurs or until the discharge activity has stopped, indicating that a flashover will not occur. To insure that a withstand level has been determined it is recommended that three trials be made at the withstand voltage level. The insulators must be completely cleaned and recontaminated for each trial.

Table 1A.1
Preferred Resistivities

Suspension Resistivity ρ_{20}	$\Omega \text{ M}$	0.83	1.7	3.3	6.7
Approximate equivalent surface resistivity ρ_{s20} (see Appendix 1C)	Ω	25×10^3	50×10^3	100×10^3	200×10^3

1A.2 Close Spray Method. This method gives results quite similar to the flow-on method. The contaminating slurry is the same as that for the flow-on method but it is applied by spraying from nozzles that give a coarse spray with a spray angle of about 90° . Four nozzles spaced radially about 30 cm from the insulators will give a satisfactory coating. After a stabilizing period of 3 to 5 min a low 60 Hz voltage is applied and the leakage current measured. The voltage is then increased rapidly until a flashover occurs. Without washing the insulating surface, another coating of contaminant is applied and the flashover test is repeated. This procedure is continued until a stabilized surface coating is obtained as indicated by a leakage current which is stable within 10 percent. The insulators are then given a final coat of contaminant and the required 60 Hz withstand voltage is applied and held until either a flashover occurs or the contaminant dries out as indicated by a large decrease in the leakage current.

1A.3 Clean Fog Method. The coating material should be prepared as a suspension in water having the following composition:

- 100 g diatomaceous earth (diatomite)
- 10 g silicon dioxide (SiO_2), particle size $2\mu\text{m}$ – $20\mu\text{m}$ (for example aerosil)
- 1000 g water (ordinary tap water may be used).

Sodium chloride (NaCl) added to give required resistivity.

Suspensions of other composition such as those used in the flow-on method may be used, if they give the required effects. In such cases, the deposit on the surface of the test object should absorb about the same amount of water as when the above suspension is used and result in a surface resistivity as given in Table 1A.1.

1A.4 Solid Coating and Wetting Procedure. The suspension is sprayed on to the clean surface of the test object (see 1.3.4.1) using one or more spray nozzles, which may be conventional spray guns of the type used for painting purposes. The resulting layer should be uniformly distributed as far as possible over the whole of the insulating surface of the test object.

It is permissible for the coating to dry out before starting the test; hence it may be applied in any convenient place and, if necessary, well in advance of the time of testing.

The coated test object is set up in the high-voltage testing area. Its whole surface should then be uniformly wetted by means of a fine mist or fog, until minimum surface resistivity is obtained (usually in about 15–20 min). This may be done using any convenient source of steam (avoiding temperature gradients on the test object) or any form of fine mist generator. The surface resistivity, measured and corrected to 20°C ac-

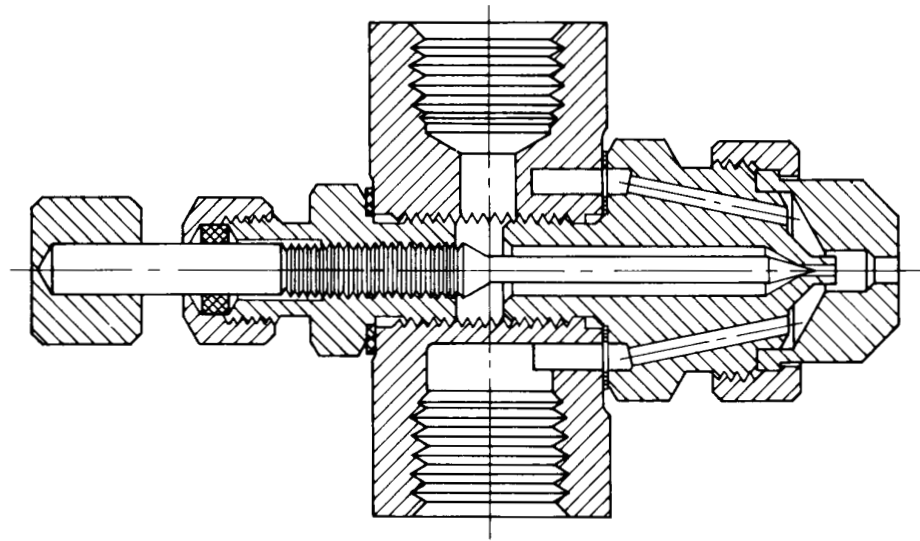


Fig 1A.1
Example of Fog Nozzle — Concentric Air and Liquid Orifices.

cording to Appendix 1C, should be approximately equal to the appropriate value ρ_{s20} given in Table 1A.1. An example of a suitable fog jet is shown in Fig 1A.1 (see Note 3).

During the wetting, it is important that no dripping from the edges of the insulator takes place. The wetting is continued during the period of voltage application.

Precautions should be taken to ensure that neither the materials nor the

processes used should introduce a hazard for personnel.

NOTES:

(1) An example of a suitable commercial available pyrogenic silica is grade H-5 obtained from the Cab-O-Sil Co, Cabot Corp, Boston, Mass.

(2) An example of a suitable commercial available wetting agent is Photoflo 2100 equivalent quantity of Photoflo 600 manufactured by Eastman Kodak Co.

(3) An example of a suitable commercial available nozzle is Pneumatic Atomizing Nozzle, 26B, made by the Spraying Systems Co.

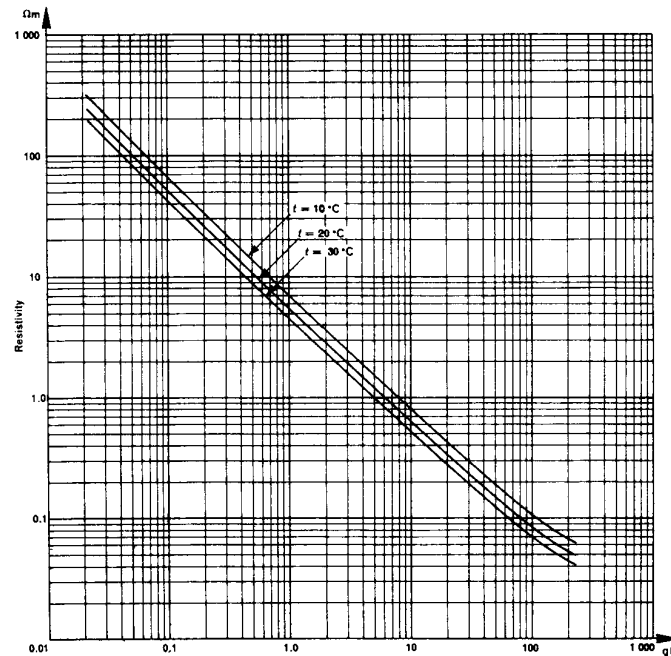
Appendix 1B

(This Appendix is not a part of IEEE Std 4-1978, IEEE Standard Techniques for High-Voltage Testing, Section 1.)

Production of Saline Fog

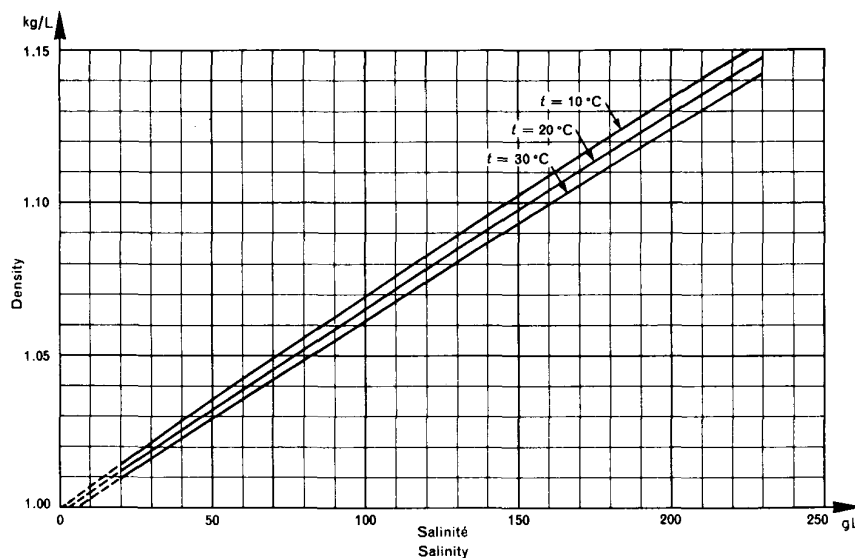
In this appendix, details are given as an example of one way of producing saline fog for artificial contamination tests made by the saline fog method.

1B.1 Preparation of Salt Solution. The salt solution should be made up to the required salinity from sodium chloride (NaCl) of commercial purity and ordinary



NOTE: The salinity is expressed in grams per liter as determined nominally at a temperature of 20°C.

Fig 1B.1
Resistivity of Solution of Sodium Chloride (NaCl) in Water, as a Function of Salinity at Solution Temperature t of 10°C, 20°C, and 30°C.



NOTE: The salinity is expressed in grams per liter as determined nominally at a temperature of 20°C.

Fig 1B.2
Density of Solution of Sodium Chloride (NaCl) in Water, as a Function of Salinity at Solution Temperature t of 10°C, 20°C, and 30°C.

tap water. The concentration should be within ± 5 percent of one of the following values: 2.5, 3.5, 5, 7, 10, 14, 20, 28, 40, 56, 80, 112, 160, or 224 g/L of solution.

The concentration may be determined by measuring either the resistivity or the density of the salt solution. Figs 1B.1 and 1B.2, give the values of the resistivity and the density, respectively, as functions of the salt concentration at 10°C, 20°C, and 30°C. (See Fig 1.2, for a larger range of variation of resistivity with temperature.) The measurement of density for concentrations of 20 g/L or less is not recommended, however, because for this measurement, a very high degree of accuracy is necessary to determine the

concentration within the specified tolerance.

1B.2 Details of Spraying System. The fog is produced in a test chamber by means of a number of jets. One type of jet in common use is shown in Fig 1B.3. Each jet has two nozzles, one acting as an air outlet and the other as an outlet for the salt solution. The compressed air thus flows across the solution nozzle and produces a fine mist of the solution.

The air nozzles should be provided with filters, oil-free air at 700 kPa (7 atmospheres) above the atmospheric pressure, with a tolerance of ± 4 percent.

The solution nozzles should be supplied with the specified salt solution

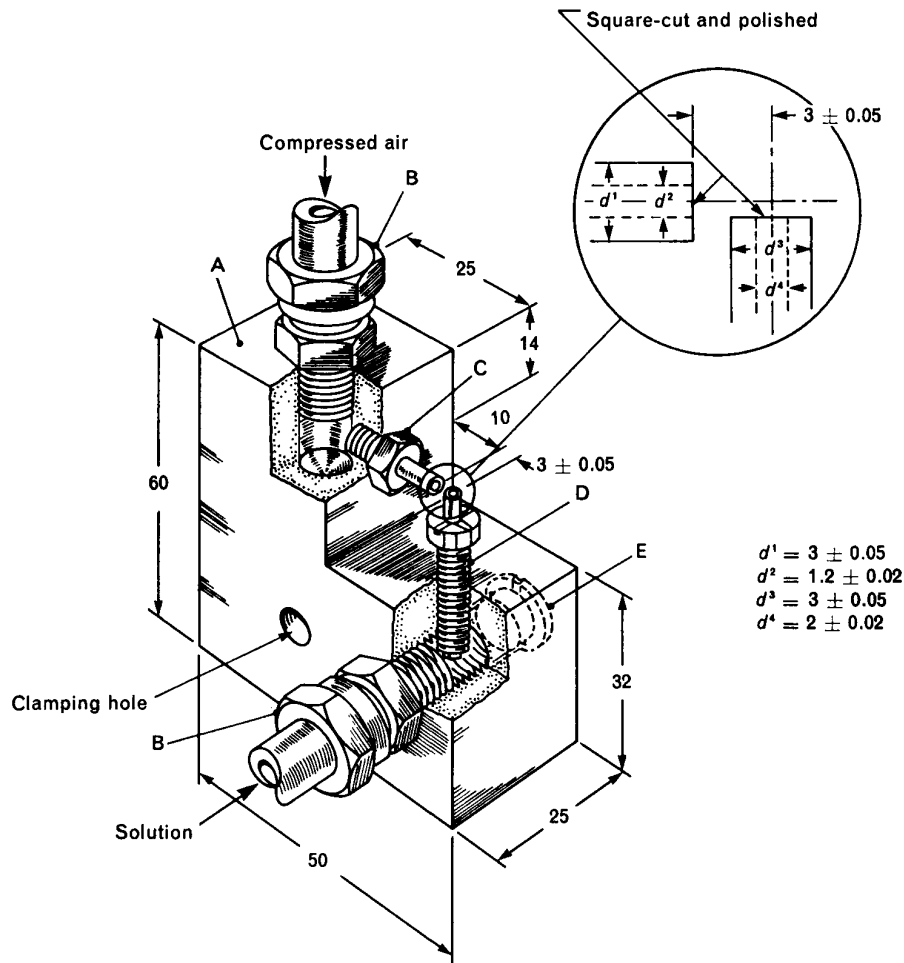


Fig 1B.3

Saline Fog Jet; See Appendix 1B. Dimensions in millimeters.

- A — plexiglass body, B — standard coupling for 8 mm nominal bore tube (stainless steel), C — stainless steel (6 mm nominal SI thread with 1.6 mm bore tube), D — nylon (6 mm nominal SI thread, 16 mm long screw with concentric stainless steel tube), E — plexiglass plug.

at a pressure adjusted so that the flow of the solution through each nozzle, with no air passing through the air nozzle, is $0.5\text{L/min} \pm 10$ percent for the period of the test; the tolerance on the total flow to all spray jets is ± 5 percent of the nominal value. Consequently, the solution pressure must also be kept constant throughout a test.

The jets are mounted 0.6 m apart in two straight rows, parallel to the center line of the test object (one on each side), each row being about 3 m from it and in the same plane, with the jets in each row directed towards one another. Each row should extend at least 0.6 m beyond the ends of the insulation section of the test object; the latter is mounted vertical-

ly, horizontally, or inclined as prescribed by the appropriate apparatus standard but should be so placed that the lowest jet is at least 0.6 m above the floor.

NOTES:

(1) It has been demonstrated that the distance of each row of jets from the axis of the test object significantly influences the measured test results. However, for variations up to ± 30 cm from the distance specified above, this effect is not appreciable.

(2) The technique which is described above has been used satisfactorily for insulators and similar objects with test voltages up to about 600 kV rms. However, for large test objects and for higher voltages, modifications to this system may be needed. In particular, it may be necessary to use more than two rows of jets and the clearance distances may have to be increased. In such cases, a measurement of the degree of the contamination of the test object is recommended (See Appendix 1C).

Appendix 1C

(This Appendix is not a part of IEEE Std 4-1978, IEEE Standard Techniques for High-Voltage Testing, Section 1.)

Measurement of the Degree of Contamination

The degree of contamination of the surface of the test object can be specified by one or more of the following characteristics, see 1C.1 and 1C.2, below.

1C.1 The Surface Resistivity of the Insulating Surface. To determine the surface resistivity of an insulating surface, the leakage resistance R_t is measured between two bare electrodes of the test object. From this resistance, the surface resistivity is calculated using a form factor derived from the geometry of the insulating surface, see below.

In general, to give consistent results, the alternating voltage used for the resistance measurement should be about 2 kV/m of the leakage path. However, in the case of the “flow-on method,” this voltage may cause drying and a lower voltage (about 500 V/m) should be used.

The leakage resistance R_t is corrected to 20°C by means of Fig 1.2, to give the value R_{20} . The surface resistivity ρ_{s20} is calculated from:

$$\rho_{s20} = \frac{R_{20}}{f}$$

where f is the form factor of the insulating leakage path defined by:

$$f = \int_0^l \frac{dx}{b(x)}$$

where

l = total length of the leakage path
 dx = length of an element of the leakage path, at distance x along this

path measured from one electrode (hence $0 \leq x \leq l$)

$b(x)$ = breadth (or circumference) of the leakage path at distance x .

The form factor is most easily evaluated by graphical integration of finite elements.

Note that the determination of the surface resistivity using the resistance and form factor may give incorrect results if the surface resistivity is not reasonably constant along the length of the test object or the measured part thereof.

1C.2 The Equivalent Amount of Sodium Chloride per Square Centimeter of the Insulating Surface. The contaminated insulating surface or a certain part of it is washed with distilled water, all of which is carefully collected. The resistivity of the collected water is measured and correction to 20°C by the correction curve of Fig 1.2. The equivalent quantity C of sodium chloride in grams per liter in the solution is determined by the use of Fig 1B.1. From this, the equivalent amount M of sodium chloride per unit surface is determined in milligrams per square centimeter by:

$$M = \frac{CV}{A}$$

where

A = the area of the cleaned surface, in cm^2

V = the volume of the collected water, in cm^3 .

Section 2: Test Procedures

2.1 General

2.1.1 Scope and Object. This standard is applicable to: (1) dielectric tests with direct voltage; (2) dielectric tests with alternating voltage; (3) dielectric tests with impulse voltage; and (4) tests with impulse current.

The objectives of this standard are: (1) to define terms specifically relating to the above tests; (2) to describe methods for generation and measurement of test voltages and currents; (3) to describe test methods; and (4) to describe methods for the evaluation of test results and to indicate criteria for acceptance or refusal.

2.2 Tests with Direct Voltage

2.2.1 Definitions for Direct-Voltage Tests.

2.2.1.1 Ripple. Ripple is the periodic deviation from the arithmetic mean value of the voltage. The amplitude of the ripple is defined as half the difference between the maximum and minimum values. The ripple factor is the ratio of the ripple amplitude to the arithmetic mean value.

2.2.1.2 Value of the Test Voltage. The value of the test voltage is defined by its arithmetic mean value.

2.2.2 Test Voltage.

2.2.2.1 Requirements for the Test Voltage. The test voltage, as applied to the test object, should be a direct voltage with no more than 5 percent ripple factor, unless otherwise specified by the appropriate apparatus standard. Note that the presence of the test object may affect the ripple factor.

2.2.2.2 Generation of the Test Voltage. The test voltage is generally obtained by means of rectifiers, but sometimes by electrostatic generators. The requirements to be met by the test voltage source depend considerably upon the type of apparatus which is to be tested and on the test conditions. These requirements are determined mainly by the values and nature of the test current to be supplied, the important constituents of which are indicated in 2.2.4.

The output current rating of the source should be sufficient to charge the capacitance of the test object in a reasonably short time (see 2.2.3.1). In the case of objects having high capacitance,