THE JOURNAL OF THE JANAF FUZE COMMITTEE

(JOINT ARMY-NAVY-AIR FORCE)

HUMIDITY AS A FACTOR IN FUZE DESIGN AND EVALUATION

Serial No. 26

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PREPARED BY A.W.BALDWIN
U.S.NAVAL ORDNANCE LABORATORY, WHITE OAK

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HUMIDITY AS A FACTOR IN FUZE DESIGN AND EVALUATION

INTRODUCTION

Fuzes consist of many intricate, small parts which must remain in new condition for a shelf storage life of five to twenty years. After withdrawal from storage, the fuzes may be transported for many miles on many occasions and may remain in temporary storage for periods of months or even years. During this dormant but long life, most fuzes cannot be inspected, cleaned, lubricated or reworked. Even if the fuze can be inspected and repaired during its storage period, the avoidance of deterioration by design is economically prudent. The design of the fuze must provide the quality of materials, fabrication, workmanship and protection to assure a perfect fuze when the crucial time of its operation arrives. During the design and development of a fuze the engineers make many tests to determine the weak points under various environmental conditions. One factor which cannot be ignored is the effect of humidity or water vapor on the fuze.

Water vapor in the atmosphere, commonly referred to as humidity, is one of the most important factors of the natural environment because of its ceaseless, though somewhat mild, effect on equipment. The design of military equipment must of necessity provide for adequate operation under all conditions of humidity since military operations can seldom be planned with any allowance for humid conditions. Equipment which is designed and manufactured without a reasonable degree of moisture resistance can hardly be expected to give satisfactory service under the extremes of humidity found in nature.

TERMINOLOGY

Many colorful but somewhat inaccurate terms are used to describe atmospheric conditions. These terms serve their purposes, but in recording engineering data, terminology must be carefully and correctly used. The terms for which conflicting definitions may be found in technical references are defined below as used by the author in this article. It is believed that other technical terms are adequately defined in any dictionary or engineering handbook.

Relative Humidity of any mixture of air and water vapor is the ratio of the weight of water vapor in the mixture to the weight of water vapor in saturated air at the same dry-bulb temperature and (barometric) pressure. Psychrometric charts provide data on the relationship of Dry-Bulb, Wet-Bulb, and Dew-Point temperatures and Relative Humidity.

Humidity Ratio is the mass of water vapor per unit mass of dry air in a vapor-air mixture. Humidity ratio has been called specific humidity and this term still is occasionally used.

Dry-Bulb Temperature is the temperature of the mixture of air and water vapor at rest. It is measured with an instrument which is neither affected by the humidity nor thermal radiation.

Dew-Point Temperature is the temperature at which condensation of water vapor will occur if the mixture of air and water vapor is cooled at constant pressure. It is the saturation temperature corresponding to the existing humidity ratio and pressure.

Wet-Bulb Temperature is the reading indicated when a thermometer bulb is covered with absorbent material, wet with distilled water, and exposed to the atmosphere permitting evaporation to cool the water and hence the bulb. In thermodynamics, the Wet-Bulb Temperature is defined as the temperature at which either liquid or solid water, by evaporating into air, can bring the air to saturation adiabatically at the same temperature.

Saturated Air is the mixture of air and water vapor at equilibrium when no additional moisture can be added to the mixture as vapor. The Dry-Bulb, Wet-Bulb, and Dew-Point temperatures are all the same at this condition. Frequently this condition is defined as one in which the mixture can coexist in equilibrium with liquid water presenting a flat surface to it. Saturated air does not contain fog, rain or water droplets.

MOISTURE EFFECTS

The effects of moisture on equipment are as varied as one can find in any category of environmental effects. Although nearly everyone has had experiences with the detrimental effects of high humidity, the author would like to mention a few situations which are favorable for the degradation of materials to exemplify the broad scope of the problems.

Corrosion of metal surfaces is accelerated by the continual wetting and washing by condensation.

Damp surfaces tend to hold contaminants which may cause very high rates of deterioration.

Electrical equipment, particularly insulation and contact surfaces, may be adversely affected if attention is not given to the selection of proper materials for the proposed service conditions.

The design of the metal parts can cause or inhibit the accumulation of moisture within the enclosures.

Water is a reasonably good lubricant and may decrease the coefficient of friction to the point of causing failure of gripping surfaces to perform their functions properly.

Hygroscopic materials frequently cause degradation or failure of a system through swelling, shrinking, warping, softening, and changes in electrical characteristics.

The potential effects of partial pressure of the atmosphere due to water vapor can be more readily appreciated after devoting a few moments to the vapor pressure or steam tables. As readily seen in Table 1, at 90°F in a saturated atmosphere, the water vapor pressure is nearly 0.7 psi. This pressure will cause water vapor to move into open or leaky mechanisms or containers in which the vapor pressure is lower. Subsequent lowering of the temperature of the leaky mechanism or container may cause condensation. Although condensation is generally undesirable, relative humidity above 60%, which is far short of condensation, can usually cause corrosion of unprotected ferrous parts.

Table 1
Properties of Saturated Steam

Temperature	Pressure	
°F	Lb/sq in.	In. Hg.
-80	0.00011	0.00024
-65	0.00035	0.00071
-40	0.00196	0.00379
-20	0.00618	0.0126
0	0.01849	0.03764
20	0.050[illegible]5	0.1027
32	0.08[illegible]58	0.1803
40	0.12164	0.24767
50	0.17799	0.36240
60	0.256	0.522
70	0.363	0.739
80	0.507	1.0[illegible]2
90	0.698	1.422
100	0.950	1.933
110	1.275	2.597
120	1.693	3.448
130	2.224	4.527
140	2.890	5.884
150	3.719	7.573
--	--	--
212	14.696	29.921

Fungi may be present in prolific quantities, but generally they will not grow or cause trouble if the relative humidity is maintained below 50%. However, at a high relative humidity (about 90%) and dry-bulb temperatures around 90°F, fungi will grow profusely if nutrients are present. Under these conditions, a device constructed with fungi inert materials is very desirable, and sealing with an enclosure will exclude the fungi and its excretions.

Corrosion or oxidation of ferrous metals is accelerated in high relative humidity atmospheres. Experiments have shown that oxidation is essentially arrested by maintaining a relative humidity below 40%. The 40% figure is not necessarily the best or only suitable condition. Many other items must be considered such as the temperature, pollution in the atmosphere, and the material being protected. In some situations, a relative humidity up to 60% is satisfactory. Protective coatings and sacrificial metals provide adequate protection for some devices, but more generally small mechanisms must be constructed of non-corrosive materials for service in high humidities.

Rain is usually rather clean water and by itself probably causes very little permanent damage to stationary items. Many foreign materials which accumulate on a device may need only water to form a highly acidic or alkaline compound which may attack the device. At the other end of the scale, some corrosion products tend to give protection to the parent metal until washed away by the rain. The relative humidity is increased by rain and the never-ending deterioration by high humidity is activated. The proper choice of materials and configurations for ordnance items can reduce the effects of rain to a negligible level.

Low relative humidity may be a desirable climatic environment for certain fuzes but other undesirable atmospheric conditions may accompany low humidity. Some of the desirable effects are that the rate of corrosion of metals is lower, and the resistance of electrical insulation is generally higher in a low humidity atmosphere. The absence of water vapor has very few other effects on fuzes. A predominantly dry climate frequently has a dusty atmosphere. Protection of a fuze against the adverse effects of dust may be as difficult as protection against high humidity. However, the methods of protection against both moisture and dust are about the same. Either the mechanism should be open to prevent the accumulation of dust and condensed water vapor, or it should be sealed against the entry of dust and moisture. One need only observe the excellent service from his moisture and dust-proof wristwatch to realize the advantages of a sealed enclosure.

DESIGN FOR HUMIDITY ENVIRONMENT

Equipment for military operational employment throughout the world under all conditions of weather must be designed to withstand the humidity effects because the user is physically unable to provide protection except in very limited ways. For example: if a fuze must be kept in its sealed package until the crucial moment for its use arrives, the user may encounter some serious limitations. Generally, any special procedures in service detract from the primary mission of the individual.

If the designer is aware of and alert to the effects of humidity on "all-weather" equipment, he can provide immeasurable protection frequently without increasing the complexity or cost of the end product. Many protective devices not only reduce the humidity effects but eliminate or reduce many other adverse effects and often enhance the design from a ruggedness and usefulness standpoint.

Seals

Some items are hermetically sealed for protection against moisture, dust, insects, air-borne contaminants and human tinkering. Hermetic seals are made by fusing metal to metal, metal to glass, metal to ceramic or other equal systems. A leak test commonly used on this class of seals is the helium mass spectrometer leak test. An item such as a special weapon device with a hundred electrical pin connectors can be sealed to provide a total leak rate of less than 1 x 10^{-6} atmospheric cc per second. Assemblies with metallic seals, when tested with a radioactive gas and calibrated detecting and measuring devices, will indicate a leak rate of less than 1 x 10^{-13} atmospheric cc per second. Past practice has shown that fuzes with a total leak rate of less than 1 x 10^{-6} atmospheric cc per second have been satisfactory in stockpile storage for over seven years and have a projected life of over 10 years with respect to gas leakage.

Waterproofing and other degrees of sealing may be adequate for some items when hermetic sealing is not practical.

Desiccants

Installing desiccants in an enclosure is a practical means of maintaining the humidity below the damaging range.

Desiccant is available in non-dusting packages and when these packages are securely fastened in a device, the system is generally satisfactory. However, a leaky enclosure, even with a desiccant, will eventually admit enough moisture to equalize the conditions inside the enclosure with the ambient atmosphere. Many variations of desiccant assemblies are available such as an assembly using "Tell-Tale" desiccant which changes color as the moisture content increases. Inspection windows may be included in the item to afford observation without opening the item.

Materials

Hygroscopic materials should be avoided but if they must be used, provisions must be made for the resultant effects. Most organic materials exposed to the atmosphere absorb or release moisture until the vapor pressure in the material is equalized with the atmospheric vapor pressure. The materials expand as the water content increases and contract as the water is released. This property of organic materials is the basis for the operation of hygrometers and is discussed later in this article under instruments.

Fungi inert materials should be used unless there is no substitute for a carefully selected material which is subject to fungi damage. Protection of the material must then be provided.

Corrosion

Surface finishes and protective coatings can be useful for protection from the weather, and frequently these coatings enhance the appearance. Surface coatings of non-corrosive or sacrificial metals frequently are more practical than paints, but on many designs the use of a corrosion resistant metal for the part will provide a stronger part with an attractive surface finish needing no further protection.

Every design which will be or even may be, exposed to the atmosphere or immersed in water should be examined for potential damage by electrochemical corrosion. Those combinations of materials which are subject to damage should be changed before the design is released for production. Electrochemical corrosion is localized corrosion resulting from exposure to an electrolyte of dissimilar metals in contact or coupled with one another. A special, but frequent, situation is a pitting type corrosion which occurs on a metal containing microscopic or macroscopic areas dissimilar in structure or composition. This is essentially an electrochemical couple within the metal. The electrolyte may be atmospheric humidity, contaminants, or a liquid in which the item is immersed.

An electrical short-circuit is formed by the dissimilar elements in contact: the electrolyte is the corroding medium, and an electric current is produced. The element having the more anodic solution potential is sacrificed and the cathodic material is unattacked. For example, copper is cathodic to iron, and in a structure of the two metals, the iron will corrode without damage to the copper. However, iron is cathodic to magnesium, and the iron in this combination will not corrode until the magnesium is essentially consumed by corrosion.

There are many combinations of metals and electrolyte in which the corrosion does not proceed in accordance with the common electromotive series. The potential differences between metals varies as the corroding environment changes. Properties of a few common metals are listed in Table 2 below to illustrate the coupling effect.

Table 2
Electromotive Series

Metal	Ion	Normal Electrode Potential, volts
Gold	Au+++	+1.36
Mercury	Hg++	+0.799
Silver	Ag+	+0.798
Copper	Cu++	+0.344
Hydrogen	H+	0.000
Lead	Pb++	-0.12
Tin	Sn++	-0.14
Nickel	Ni++	-0.23
Iron	Fe++	-0.44
Aluminum	Al+++	-1.33
Magnesium	Mg++	-1.55

If the design cannot be changed to eliminate the couple formed by two dissimilar metals in contact, the designer should determine which metal will be sacrificed and adjust the design to minimize the effects of corrosion. Tests are generally necessary to complete the study of the design. Stress-corrosion cracking occurs when more or less continuous zones exist within the structure of the metal or alloy which are more susceptible to corrosion than the rest of the metal. Usually the attack in these zones occurs because they are anodic to the rest of the metal. Electrochemical corrosion of the anodic material creates fissures in the metal. If high tensile stresses are present, the fissures increase the magnitude of local stresses which tend to further open the fissures, exposing new anodic material to sustain the process.

Stress-corrosion cracking (season cracking) of brasses and some other copper alloys occurs when metals are stressed by cold working or by loads externally applied in service. The primary factors of stress and corrosion are influenced by the temperature, time and the presence of ammonia, carbon dioxide, oxygen and moisture. The stress-corrosion cracking of brasses may be overcome by the use of alloys which have a high resistance to this type of failure. Also, the tendency toward stress corrosion cracking of brasses may be reduced by heat treatment to relieve thermal stresses resulting from cold working. Plating, painting, coating, or controlling the atmosphere to which brasses are exposed tends to reduce stress-corrosion cracking.

Extensive discussions on corrosion and chemical reactions of metals are available in such books as references (a), (b), and (c).

Packaging

Packaging a fuze in a vapor-tight container will protect the fuze during storage, but the fuze must withstand the environment after assembly to a weapon. Therefore, the exposed surfaces after assembly must be designed for exposure to the natural environments.

ENVIRONMENTAL CRITERIA AND TESTS

Environmental engineers, scientists, technicians, and other interested people have created many laboratory and field tests for evaluating devices with respect to humidity and humidity-related environments. Most tests have been created for specific applications, and usually the time factor, temperature, or other parameters have been distorted to obtain data quickly. One must be very selective in his application of tests and even more judicious in the use of data derived from the tests. Prior to the selection or creation of a test, a review of the environmental criteria is useful since these data are basic to the evaluation. The climatic limits to be expected may be obtained from many documents such as the following which are also shown as references (d) through (h).

MIL-STD-210 Climatic Extremes for Military Equipment.

MIL-STD-446 Environmental Requirements for Electronic Component Parts.

Handbook of Geophysics. Air Research and Development Command, United States Air Force. MacMillan Co., New York. Revised Edition 1960.

AR 705-15 Research and Development of Materiel. Department of the Army.

NavOrd OS 6341 Miscellaneous General Ordnance Design Requirements.

After establishing the environmental criteria for the item under consideration, tests may be selected or created which may accelerate the humidity effects. A few tests which have been used with various degrees of success are listed below and also listed as references (e) and (i) through (n).

MIL-STD-446 Environmental Requirements for Electronic Component Parts. (Same as the second one above)

MIL-STD-108 Definitions of and Basic Requirements for Enclosures for Electric and Electronic Equipment.

MIL-STD-202 Test Methods for Electronic and Electrical Component Parts.

MIL-STD-304 and 354 Temperature and Humidity Test.

MIL-STD-305 and 355 Vacuum-Steam-Pressure Test.

MIL-E-5272 Environmental Testing, Aeronautical and Associated Equipment, General Specification for.

MIL-STD-810 Environmental Test Methods for Aerospace and Ground Equipment.

A natural exposure is the best test if time permits. Many Government and privately owned test sites are established for exposure of materials and devices to any desired climate under the control and observation of competent, experienced, environmental engineers. Data, thus obtained, can be analyzed to determine the effectiveness of the materials and configuration to withstand humidity extremes.

INSTRUMENTS

Any device for measuring the amount of water vapor in the atmosphere is a hygrometer but many users prefer to separate the instruments into the categories of hygrometers and psychrometers. There are many satisfactory instruments available for the measurement and control of humidity, and an extensive tabulation of instruments is given on pages 20-14 to 20-16 of reference (f). Detailed discussions of instruments are available in many sources such as reference (o). Only the principles of operation by classes of instruments are discussed below.

Psychrometers - The process of evaporation of water absorbs heat from the surrounding atmosphere and other objects. This principle is used to obtain a "wet-bulb" temperature reading for calculation of the humidity. The depression of the temperature varies directly with the rate of evaporation and the rate is inversely proportional to the amount of water vapor in the atmosphere. Generally the bulb of a thermometer or the active element of a temperature sensing device is covered with a wick which is wetted by a reservoir of water. The thermometer is so located that a stream of air passes over the bulb at a rate of at least 15 feet per second. The temperature of the wet bulb thermometer and the dry bulb temperature of the air are used to determine the relative humidity. Psychrometric charts and tables are a convenient means for converting the temperatures to relative humidity.

Organic Hygrometers - Many organic materials change in physical dimensions in relationship to the water vapor in the surrounding atmosphere. Those materials such as human hair, wood, paper, silk, animal hair and animal membranes which consistently expand and contract with the change in water vapor of the atmosphere are used as the active material in hygrometers. These materials require frequent calibration but the convenience of unattended operation is often desirable. The indicators are simple and inexpensive and can easily provide direct reading in terms of humidity.

Dew-Point Hygrometers - The temperature at which water vapor in the atmosphere condenses on a clean non-hygroscopic surface is usually considered as the dew point temperature. Dew point instruments contain a mirror-surfaced metal to which a thermocouple is welded. The mirror is cooled from the back by expanding a fluid such as freon or carbon dioxide. A sample of the atmosphere to be measured is passed over the mirror while the temperature of the mirror is lowered until condensation occurs. By using psychrometric charts and tables or by making calculations, the relative humidity may be determined. This principle is useful in measurement of high temperature gases such as flue gases or chemical process gases. Photoelectric cells are sometimes used to detect the condensation on the mirror.

Electrolytic Hygrometers - The moisture content and the electrical resistance of many salts vary with the water vapor content of the atmosphere to which the salt is exposed. At least two types of instruments have been developed which are described below.

The Dunmore hygrometer consists of two parallel fine wires wound on a non-conductive tube. The assembly is coated with an electrolytic film usually containing lithium chloride which forms an electrical resistance between the two wires. The resistance of the salt varies with the ambient moisture and presents a measurable value which can be calibrated in terms of relative humidity. The instrument was first developed for radio-sondes, but its use has been extended to many applications.

The Weaver hygrometer consists of two electrodes connected by a gelatinous, hygroscopic, electrolytic film. The assembly is generally made in a threaded plug for use in measuring the humidity in closed vessels. The electrical resistance is measured with the active element exposed to the unknown gas. The active element, usually by a manifold and valve system, is transferred to a known gas mixture. The pressure of the known gas is varied until the equivalent electrical resistance is obtained. By calculations the relative humidity or vapor content of the unknown gas can be determined.

Chemical Hygrometry - The humidity of an atmosphere can be measured by extracting and weighing the water vapor from a known sample. Desiccants such as sulphuric acid, phosphorous pentoxide, calcium chloride, lithium chloride and silica gel may be used according to the accuracy of measurement desired. Another similar method is to freeze the moisture out of a stream of atmosphere using dry ice and weighing the resulting ice.

SUMMARY

Many test reports have been written on the effects of humidity on military equipment. Many field reports of degradation of material by humidity have emphasized the tremendous losses from this factor alone. Several books, such as references (b) and (p) and hundreds of reports abstracted in references (q) and (r) treat the subject from many points of view. No one has yet been able to prescribe a simple or direct set of rules to avoid adverse or deteriorating effects of humidity, but none the less, inattention to the subject may cause major problems. The reports show that the action to prevent moisture deterioration of a fuze must be taken in the design phase since protection cannot be provided in storage and in the field. It is indeed encouraging to obtain surveillance reports on many items after several years of storage stating "excellent condition."

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HUMIDITY AS A FACTOR IN FUZE DESIGN AND EVALUATION, by A. W. Baldwin, Naval Ordnance Laboratory, White Oak, Maryland. 12 Dec. 1962. 13p. UNCLASSIFIED

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2. Environment
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