Effect of relative humidity and moisture upon different industries. The facilities of thermal metrology laboratory for calibration of its measuring instrument to improve product quality, protect users and to increase mutual trades

N.I. El-Sayed& M.M. Mekawy

Humidity measurements are now considered very important in terms of cost savings and product quality, and are often required for safety reasons by agencies such as the Environmental Protection Agency (EPA), Federal Aviation Administration (FAA), Food and Drug Administration (FDA), National Fire Protection Agency (NFPA), the Nuclear Protection Agency (NPA), and similar organizations in Europe and Asia.

Moisture content is the single most important quality characteristic that determines the safe storage potential for cereal grains and oilseeds. Grain that is too high in moisture content is subject to attack by grain storage fungi and stored grain insects. Fungi produce toxins such as aflatoxins and fumonisins that are serious health hazards to man and animals that use these products for food and feed.

This essay will list a number of the more common applications and discuss the types of sensors used and its calibration facilities at NIS. Some important applications will be discussed in detail; others will be briefly outlined, indicating the need and purpose of such measurements.

Key words: Humidity, moisture, Facilities for calibration of humidity sensors, Facilities for calibration of moisture sensors, uncertainty for calibration of humidity sensors

The most common applications are:

I. Heat Treating

Heat treating is an operation that is used to change the mechanical properties of a metal, such as its strength, hardness, or duct ability. Heat treatments involve heating and cooling of a metal or an alloy with regard to temperature, atmosphere, humidity and time to achieve the desired qualities. Inert gases are used during the heat treatment of metal to prevent oxidation ***Dew point instrumentation is used for control of water vapor.***

II. Semiconductors and computer rooms

Sophisticated microcircuits (chips) involve extremely high packing densities of individual elements and are subject to damage due to contamination and moisture. The probability of failures resulting from a single defect increases as the distance between components on the chip decreases. Levels of moisture that can cause damage are often very low (in the 1 ppm range and below). ***Chilled Mirror Hygrometer instrument provides by far the most accurate and repeatable instrument.***

Humidity measurements are also important in computer rooms where large and expensive data storage system is installed. It is a well known fact that under extreme humidity and temperature conditions, magnetic devices used for data storage could be distorted and cause catastrophic failures to expensive equipment and the loss of important stored data. Certain types of computers are equipped with water- cooled storage systems, and in such cases humidity measurements are used to detect leaks by measuring humidity changes in the air surrounding the water- cooled devices.

National Institute for Standard (NIS)

For these measurements, environmental conditions are usually right, i.e., air is clean and surrounding temperatures are close to ambient. ***Bulk polymer relative humidity sensors, capacitive or resistive sensors [1],[2] perform well under these conditions and are often used. Such sensors should be periodically recalibrated, which is normally done on site.***

III. Water Activity Measurements (food processing)[3].

Foods contain moisture in three states: free moisture, hydrogen-bonding, and ionic-bonding. Free moisture contributes to the bulk of the food and affects its packaging and shipping. More importantly, free moisture allows micro-organisms to proliferate, thus causing spoilage of food. The goal is to eliminate free moisture, while retaining ionic-bonded moisture and most of the hydrogen-bonded moisture. If the bonded moisture is removed, undesirable changes in flavor and color occur which may render the product unstable.

Water activity (*Aw)*, is defined as the free moisture available in a material and is considered to be the water that is free to enter and leave the material by absorption/desorption. as opposed to the chemically-bound moisture. It is directly related to equilibrium relative humidity (%ERH).

Since more and more quality restrictions are being placed upon finished products, processing, and preservation of materials, applications for water activity measurement have increased rapidly and are becoming more diverse and more firmly established as part of documented quality procedures. Wherever there is a need to monitor or control free water in a material, an application to measure water activity exists.

The physical-chemical binding of water, as measured by water activity *(Aw)*, can be defined as:

$$\left[\mathrm{A}w = \frac{P}{Po} = \frac{\%ERH}{100} \right]$$

Where:

P= vapor pressure of water exerted by the food

P_o= vapor pressure of pure water

%ERH= Equilibrium Relative Humidity of the food

Among other measurements, such as pH testing, the *Aw* value needs to be controlled since it is this free water that is available for micro-organisms to grow, multiply, and cause spoilage. Micro-organism growth can be controlled by suppressing water activity with different product formulations and by using additives which may be natural or artificial. By controlling *Aw*, product shelf life and safety can be improved.

The chilled mirror hygrometer provides the fastest and most accurate measurements, but is more expensive than the RH types which are widely used and also offer good performance.

IV. Paper Industry

One parameter that the long been recognized as influencing the properties of paper and cardboard is moisture. It is difficult to eliminate any difference between the ambient %RH and the %ERH, however, controls or limits can be established. A %ERH of 50% is ideal for paper since any %RH changes; say in the range of 40%-60% will have little effect on the moisture content.

From time to time, printers experience difficulties due to static electricity, such as paper sheets sticking together. This usually happens when the air and paper are too dry. When the paper and air are in the 40%-45% rnage this problem seldom occurs. Paper fiber absorbs or desorbs water depending on the ambient relative humidity. This causes swelling or shrinking of the fibers, which affects the diameter of these fibers more than their length. In a sheet of paper most fibers run parallel to the running direction of the paper machine. Accordingly, dimensional changes which are the results of moisture variations are more important along the axis that is perpendicular to the running direction of the paper machine, than along the axis parallel to it. At approximately 50% ERH a humidity change of 10% ERH results in a change of typically 0.1%-0.2% in the length of the paper. Such a humidity difference gives a dimensional variation of 1 to 2 mm (39.4to78.8mil) on a 1x1 meter (3.28x3.28 ft.) paper and could therefore cause poor and inaccurate printing. Paper running through an offset press usually gains water since it is moistened in the process. The change in the moisture content depends not only on the %ERH of the paper (40%-60%), but also on the ambient %RH. Paper in stacks or rolls shows deformation if too much moisture is exchanged with the surrounding air through the edges of the stack or roll. This is due to the uneven distribution of this moisture as it is exchanged with the ambient air during storage or transport. Water-vapor-tight packaging protects the paper and it should not be removed without first checking %ERH of paper and %RH in the ambient environment. Differences up to +5% RH will not cause problems, while a difference of 8%-10% RH could be critical***. Usually of the capacitive polymer type or some other resistance or capacitance measurement principle***

V. Medical Applications

There are many medical applications for measuring humidity, some of which will be discussed briefly below.

It is clear that there is a great need for humidity measurements in pharmaceutical companies, specifically for controlling the environment in chambers where tablets, medicines and other pharmaceutical products are manufactured and dried. Although many applications could be taken care of with ***polymer type %RH sensors, chilled mirror hygrometers are sometimes preferred because of their fundamental nature, accuracy, and traceability, which is important to satisfy regulatory agencies.***

Some applications for *Aw* testing in pharmaceuticals relate to microbiological considerations, but many concern processing to achieve correct moisture levels which facilitates filling of capsules, tablet forming, and packaging. For example, gelatin capsules are often *Aw* maintained to allow them to be sufficiently supple for filling without cracking or breaking in the process. There are many effervescent powder manufacturers who control total moisture within specified limits, by measuring *Aw* as a quality check because it is in some cases quicker and more practical.

One way the skin of the human body can provide information on the state of health is through temperature a perspiration characteristic.

Perspiration and humidity measurements have played a major role in research laboratories where clothing is tested for use by military personnel under various climactic conditions.

Although the implantation of artificial hearts has had limited success to date, considerable research is being conducted to advance this technology. Careful humidity and temperature control during fabrication of such hearts have been shown to be very important. ***Both chilled mirror and bulk polymer sensors have been used for this research.***

Accurate measurement and control of temperature and humidity in incubators for prematurely born babies is very important. ***Bulk Polymer RH sensors, both capacitive and resistance types, are frequently used for such applications***. These sensors are

also used in hatching chambers for chickens and various other animals, as well as for research purposes.
In some special medical applications, control is critical***, chilled mirror sensors have been selected.***

VI. Museums
Preserving centuries-old art is becoming more and more important. In recent years, there has been an increasing awareness of the need to maintain environmental conditions in which museum artifacts are stored and displayed. Today's conditions present additional threats, which include automobile emissions and chemical pollutants. However, nothing poses a greater threat to such art than condensation resulting from rapid humidity and temperature changes. Primarily it is relative humidity and temperature that are the major concerns as changes in these conditions affect the stability of delicate and perishable objects. Organic material, such as wood, leather, and anvas, is most susceptible to damage resulting from poor relative humidity and temperature conditions. Paintings can crack as a result of low relative humidity. And leather and fabrics can develop mold growth at relative humidity levels above 60% RH. ***Bulk Polymer RH sensors, both capacitive and resistance types, are frequently used for such applications***

VII. Meteorological Applications
Temperature and humidity measurements are of importance to weather bureaus for computer analysis and weather forecasting. ***Ground-based as well as aerial sensors are used.***

VIII. Airports
Humidity information is used to compute the "lift" encountered by airplanes taking off, or landing on an air field. Improper information can cause unstable landings, damage to landing gear, or accidents.
Several research programs are funded by defense agencies with the objective to analyze the effects of humidity and other parameters on data transmissions in the upper atmosphere and through clouds. High-flying aircraft have been used for this purpose, utilizing specially-designed chilled mirror hygrometers. Measurements are generally conducted at very low pressures and very low ambient temperatures***. Typical dew/frost point to be measured are as low as -80^{0}C.***

Humidity laboratory at NIS
As it is known that, the principle functions of NIS are the maintenance of national primary standards and giving technical leadership and advice upon request to industry and other sectors in problem related precision measurements and calibration of high precision measurement devices for scientific and technological laboratories.
As globalization and cross-border business increases, industrial sectors require equivalent and acceptable measurements. This can be achieved by issue a calibration certificates according to ISO 17025 including the environmental condition (Humidity, temperature & etc...)
According to the great importance of the measurement of humidity and moisture in different applications, also to establish methods for calibration of its sensors, thermal metrology laboratory established an advanced unit for measuring humidity, moisture and to calibrate its measuring instruments..

For establishing traceability, a measurement device is compared with a measurement standard so that a chain of comparisons going back to primary standards for the realization of the SI units is unbroken.

Types Of Standards Used

Standards used to calibrate humidity instruments fall into three classifications: primary standards, transfer standards, and secondary devices.

Below is a brief description of examples of the three classes of instruments.

Primary Standards

Precision generators[4].

These systems rely on fundamental principles and base units of measurement. Precision generators based on three different principles were developed. The methods used are sometimes referred to as the two-flow, two-temperature, and two- pressure methods. At thermal metrology (unit of humidity) a two pressure generator is used. The model 2500 Bench top Humidity Generator (used at NIS) is a self contained facility capable of producing known humidity values using the fundamental principle of " two pressure" generator developed by NIST. This system is capable of continuously supplying accurately known humidity values for instrument calibration, evaluation and verification.

The 2500 operates using an on board computer and control system to perform calculation and control function. The computer control system utilizes a multifunction STD Bus CPU in conjunction with other STD Bus principle card for control and is incorporated into the bench top humidity generator.

Humidity and temperature set point values are input by the operator from the front panel keypad. Visual indications of system status are displayed in real time on the Liquid Crystal Display. The automatic features of this system allow the 2500 to generate humidity and temperature set points completely unattended. This automated approach frees the operating technician from the task of system monitoring and adjustments, allowing him time to perform other vital tasks.

Fig.(1) model 2500 Bench top Humidity Generator (used at NIS)

Transfer Standards

Chilled Mirror Hygrometer

One of the equipments used at humidity unit, it is probably the most widely used transfer standard. It consists of a mirrored surface in contact with the gas stream to be monitored is cooled until condensation is formed. The temperature at which condensation is formed is known as the dew or frost point of the gas and directly relates to the saturation water vapor pressure of the sample. From this data any hygrometric equivalent parameter can be calculated, provided that other information such as gas temperature and pressure are also known.

Fig.(2) Chilled Mirror Hygrometer

Secondary Devices

Secondary devices are non fundamental and must be calibrated against a transferstander or other fundamental system. to provide accurate data. They require recalibration at certain about 4 time intervals

Polymer Film RH Sensors

These sensors are constructed from polymer material with a hygroscopic dielectric and designed to provide an electrical response in terms of relative humidity. Significant improvements have been made in recent years and these devices can now provide excellent low-cost service, particularly in normal ambient, and sometimes also at high temperatures.

Fig.(3) Polymer Film RH Sensors

Calibration facilities of thermal metrology lab.

Around 500 hygrometers of users are calibrated yearly at thermal metrology lab. against its standard inside a climatic chamber. The calibration certificate contain the total uncertainty (type A & B) and the traceability to SI units according to ISO 17025.
For the climatic chamber high air circulation rates achieve real conditions in accordance with DIN ISO 50011, Sec. 12, without making a whirl. Digital control technology, stress screening of the component utilized and the assignment of components suitable for the last refrigerants add to the efficiency. If a malfunction should occur a fault report many be printed out via the control system.

Fig.(4) climatic chamber

Moisture Calibration Facilities at NIS[5]

Besides of the standard method (oven dry method) the following instruments are used

GMK-508-1L Moisture Meter

The measuring principle of GMK-508-1L is based on oven method. It is equipped with a precise balance, which provides directly reading of moisture loss from 0% to 100%. It is, therefore, widely applicable for measuring moisture of all substances which can be dried by infrared heater as beans, concrete, etc.

Fig.(5) GMK-508-1L Moisture Meter

For measuring moisture in wood Ttesto 606 Moisture Meter for Wood & Materials is used this instrument is based on standards [6],[7].

Fig. (6) Ttesto 606 Moisture Meter for Wood & Materials

Calculation of uncertainty and achieving traceability.

For establishing traceability, a measurement device is compared with a measurement standard so that a chain of comparisons going back to primary standards for the realization of the SI units is unbroken.

Calculation of uncertainty[8],[9]:

After ~ ten results of moisture content were calculated, the mean was calculated from the relation

$$q = \sum_{i=1}^{i=n} \frac{qi}{n} \qquad \text{.................................(1)}$$

Where
$\boldsymbol{q}$ is the mean
$\boldsymbol{n}$ is the number of readings ≈10
$\boldsymbol{q_i}$ is the percentage of moisture content value of each sample and $\boldsymbol{i}$ is the number of the sample

Then the variance is equal to

……………..(2) $$S_q^2 = \frac{1}{n-1}\sum_{i=1}^{i=n}(q_i - q)^2$$

The standard deviation (S_q) (Type A of uncertainty) is equal to

………………………(3) $$U_{REP} = S_q = \sqrt{S_q^2}$$

Type B of uncertainty can be calculated from the following table

Table 1 – Contents of type (B) parameters of uncertainty.

Symbol	Type of Uncertainty	Source of uncertainty	Type of distribution	Divisor
U_{calb+} U_b	Valve of uncer. Of the st. meter and its monitor.	Calibration certificate	Normal	2
U_{dr}	Difference between the corrections of the st. meter between the two period of calibration.	Calibration certificates of the two periods	Rectangular	$\sqrt{3}$
U_i	The uncertainty of the readout of the meter indicator	The resolution of the monitor	Rectangular	$\sqrt{3}$

Type B uncertainty =

$$\sqrt{(Ub)^2 + (U_{calib.})^2 + (U_{Dr})^2 + (U_I)^2}$$

The combined uncertainty U_c=

$$\sqrt{(U_{REP})^2 + (U_b)^2 + (U_{calib})^2 + (U_{Dr})^2 + (U_I)^2}$$

The expanded uncertainty U_T is $U_T = U_c \times 2$

Research projects in the field of humidity and moisture carried at thermal metrology laboratory:

1- "Study and characterization of relative humidity fixed points cells in the range from "11%=97%".
M.M Halawa, E.E. Mahmoud and N.I. El-Sayed.
Thermometry Department , National Institute For Standard , Tersa Street , Giza , Egypt .
September 2002 , ISHM 2002 , The 4th International Symposium on Humidity and Moisture .

2- Realization of the humidity scale using standard salt solution fixed point cells.
E.E Mahmoud , M. M. Halawa and N. I. El-Sayed .
Thermometry Department , National Institute For Standard , Tersa Street , Giza , Egypt .
September 2002 , ISHM 2002 , 4th International Symposium on Humidity and Moisture .

3-Thin film capacitive sensors for realization of humidity scale of National Institute of Standards.
M.M Halawa, E.E. Mahmoud and N.I. El-Sayed.
October 2002 , Egypt Journal for Solids .

4**-** New calibration model for calculation of wood moisture meters using Anderson- Stuart model in amorphous materials .
N. I. El- Sayed , Maher z. Ahmed , Essam Mahmoud , and Mustafa M. Mekawy .

5- Comparison between the different methods used for measurement moisture content of wood.
N.I. El-sayed & M.Meckawy
International 5th Symposium on Humidity and Moisture ISHM May 02-05, 2006– Rio de Janeiro ,Brazil

6- Development of a new humidity sensor based on photonic crystal.
N.I. El-sayed & K.I.El-Nagar.

7- Determination of the best and fast method for the determination of moisture Content in beans.
N.I. El-sayed & M.Meckawy

8- Methods for measuring moisture content of wood and their uncertainties.

N.I. El-sayed & M.Meckawy

:

Two scientific degrees were carried out; under the supervision of Pr. Dr. N.I. El-Sayed and Dr. M. Halawa

1-PhD. In title (Study and characterization of relative humidity fixed

Points in the range from "11%-97%).
By E.E. Mahmoud
2-MSc in title "Evaluation of moisture content in wood fiber and recommendation of the best method for its determination ".
By M. Ahmed

References:

[1]) M.R. Milota, 1994. Specific gravity as predictor of species correction factors for a capacitance-type moisture meter. Forest Prod. J. 44 (3): 63-68.
[2] S.L. Quarles and T.A.,Breiner Operational characteristics of a capacitive admittance type in-kiln moisture meter. Forst Prod. J.42(3):15-22.1992
[3] Troughton, G.E. and M.R. Clarke. 1987. Development of a new method to measure moisture content in unseasoned veneer and lumber. Forest Prod. J. 37(1): 13-19.
[4]Lewis Greenspan ,J .of research of the National Bureau of standard,81A,89-96,1977
[5] ASTM D 4444-92: Standard Test Methods for Use and Calibration of Hand-Held Moisture Meters
[6] ASTM D 4442-92, 2002 Standard Test Methods for Direct Moisture Content Measurement of Wood and Wood-Base Materials, ASTM.
[7] ASTM D 444-2, 2002. Standard Test Methods for Use and Calibration of Hand-HeldMoisture Meters, ASTM.
[8] S.,Bell A beginner's guide to uncertainty of measurement,NPL,1999
[9] ISO Guide to the Expression of Uncertainty in Measurement, International Organization for Standardization, Geneva, Switzerland ,1993

Effect of relative humidity and moisture on different industries. The facilities of thermal metrology laboratory for calibration of its measuring instrument to improve product quality, protect users and to increase mutual trades

N.I. El-Sayed& M.M. Mekawy

National Institute for Standard (NIS)

Summary

There are numerous requirements and applications for measuring humidity. Through the last 40 years, the awareness and need for such measurements has been rapidly

increasing. Humidity measurements are now considered very important in terms of cost savings and product quality, and are often required for safety reasons by agencies such as the Environmental Protection Agency (EPA), Federal Aviation Administration (FAA), Food and Drug Administration (FDA), National Fire Protection Agency (NFPA), the Nuclear Protection Agency (NPA), and similar organizations in Europe and Asia.
When confronted with such requirements and regulations, the most important decision is to select the most suitable sensor and measurement method. Humidity can be measured in many ways, and excellent humidity instruments can be found in the marketplace. However, no instrument is good for all applications and if an otherwise excellent instrument is used in the wrong application, or is not calibrated unsatisfactory results will be obtained.
Moisture content is the single most important quality characteristic that determines the safe storage potential for cereal grains and oilseeds. Grain that is too high in moisture content is subject to attack by grain storage fungi and stored grain insects. Fungi produce toxins such as aflatoxins and fumonisins that are serious health hazards to man and animals that use these products for food and feed.
This essay will list a number of the more common applications and discuss the types of sensors used and its calibration facilities at NIS. Some important applications will be discussed in detail; others will be briefly outlined, indicating the need and purpose of such measurements.
The more common applications are
I. Heat Treating II. Semiconductors and computer rooms
III. Water Activity Measurements (food processing). IV. Paper Industry
V. Medical Applications VI. Museums VII. Meteorological Applications VIII. Airports

The essay include Calibration facilities of thermal metrology lab. Also how to calculate the uncertainty and to prove the traceability to SI units.

Research projects in the field of humidity and moisture carried at thermal metrology laboratory are also listed.