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**Research Article**

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# Low Cost Humidity/Temperature Calibration System

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**Abstract** A simple and low cost humidity/temperature calibration system is described in this article. This system basically is consists of a temperature controlled cabinet (refrigeration system), humidifier, temperature/humidity controller and reference hygrometer as a simple climatic chamber. It can also provide temperature calibration for built-in digital thermometer (without external temperature sensor) or thermo hygrometers. The working temperature range of the designed calibration system is started from 5 $^{o}$C to 50 $^{o}$C and from 50 % rh to 98 % rh for humidity.

The designed calibration system was tested and calibrated for the temperature and humidity in its full range and an accuracy of 0.3 $^{o}$C and 1.5 % rh was achieved.

The purpose of this paper is to describe the assembly of a low cost system to calibrate thermo-hygrometers.

**Keywords** Soft set, operations, soft ring, soft ring ideal, idealistic soft ring

## 1. Introduction

In the current years we noted, an increasing interest in the calibration of thermo-hygrometers over the world due to most laboratories, working zones and storage areas have a critical processes sensitive to ambient temperature and relative humidity.

In this work an easy assembly for a humidity calibration system is described using some basic equipment as; temperature chamber, humidifier, temperature/humidity controller and reference hygrometer. The biggest advantage of this system is simplicity and low cost that makes this system attractive for calibration of thermo-hygrometers in the small calibration laboratories of developing countries. This simple design will allow anyone who has basic information about thermo-hygrometers and climatic chambers to try it with a very reasonable cost.

## 2. Developed Calibration System

The individual components and techniques of the developed humidity calibration system will be discussed consists of the following items;

### 2.1. Temperature controlled cabinet (refrigeration system)

A temperature controlled cabinet over the range + 5 ºC to + 50 ºC are using. This cabinet is supported with a digital temperature controller with resolution 0.1 ºC. Air (air circulation system) is forced over the heater and cooling fins and through the air duct in the upper surface to ensure a uniform temperature throughout the cabinet. The front doors are an internal double glass door and external metal door to ensure that the temperature and humidity are stable enough. When calibrating thermo-hygrometer good temperature control is essential.

A temperature controlled refrigerators (mini refrigerator) can be used instead of the temperature controlled cabinet, but with an important condition is the presence of a built in temperature controller for these refrigerators.

**2.2. Ultrasonic humidifier**

An ultrasonic humidifier is used to generate the humidity in this system. This ultrasonic humidifier uses a ceramic diaphragm vibrating at an ultrasonic frequency to create water droplets that silently exit the humidifier in the form of cool fog. The mist gets forced out by a tiny fan. The ultrasonic humidifiers use a piezoelectric transducer to create a high frequency mechanical oscillation in a film of water. Ultrasonic humidifier should be cleaned regularly to prevent bacterial contamination from being spread throughout the air. The amount of minerals and other materials can be greatly reduced by using distilled water. The ultrasonic humidifier is provided with an adjustable mist control star from 0 up to 100 % with 10 % subdivision.

**2.3. Humidity controller**

A digital humidity controller with wide humidity measuring range and controlling range is used control the steam produced by the ultrasonic humidifier device with accuracy 1% for humidification and dehumidification modes.

This controller comes with a thin film humidity sensor probe. Humidity measuring range is 1% ~ 100% RH and control range is 1% ~ 100% RH.

**2.4. Reference Thermo-hygrometer**

A temperature/relative humidity recorder (Rotronic Hygrolog HL-NT data logger) was used as a reference thermo-hygrometer for monitoring and recording the temperature and humidity of the climatic chamber. This recorder is comprised of a display unit and one or two sensor units, each with both a temperature sensing element (thermistor) and relative humidity sensing device. The sensor units are connected directly through long cables. Consequently the instrument is able to monitor the temperature and relative humidity at two separated locations. The working range of this thermo-hygrometer with its external probe is -30 to 70 °C for temperature and from 0 to 100 %rh for humidity with accuracy ±1.5 %rh for humidity and 0.2 $^{o}$C for temperature.

**2.5. Monitor Camera**

A low cost video camera, "Web Cam" is used in conjunction with a PC to follow and read your devices under test during the calibration process that can easily record the measurements manually, where the used chamber has an opaque metallic external door.

**3. Design of the calibration system**

The design of the developed calibration system used to calibrate the hygrometer, temperature/relative humidity recorders and data logger will be shown in the following figures (Fig. 1 and Fig. 2).

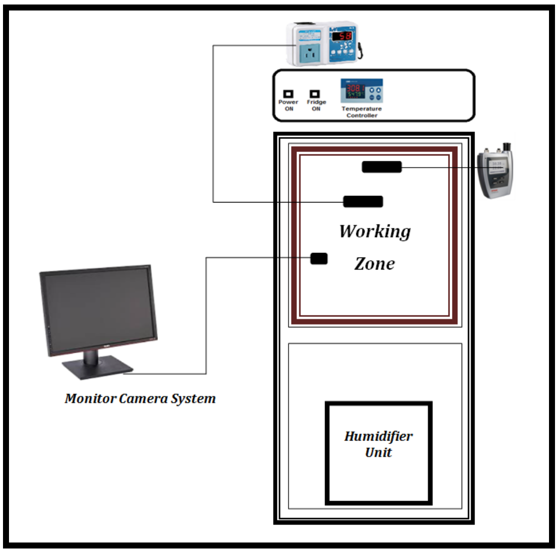


*Figure 1: Illustration diagram of the developed humidity calibration system*

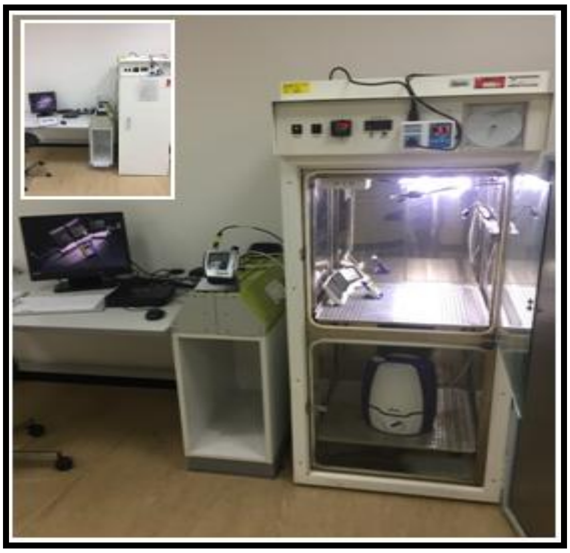

*Figure 2: Actual photo for the developed humidity calibration system*

**4. How does the chamber work?**

As it's known, relative humidity is the ratio of partial pressure of water in the air to the equilibrium vapor pressure of water at that temperature (measured in rh%).

$$H_R = (p_w/p_s) \times 100$$

Where;

$H_R$ is the relative humidity (% rh)

$p_w$ is the partial vapor pressure of water

$p_s$ is the saturation vapor pressure of water (at the same temperature)

To generate a constant flow of air at a specified temperature and absolute humidity, there are different methods, where the flow rate of water per unit time is then given by [1]:

$$qw = (pw \times HR \times qA) / 1000 = (CV \times M \times qA) / (22.4 \times T_{273} \times (P/Patm))$$

Where;

$q_w$ is the water flow rate (g/min)

$H_R$ is the fractional relative humidity

$q_A$ is the flow rate of air (L/min)

M is the molar mass (g/mol)

$C_V$ is the concentration (volume per volume)

P is the experimental pressure

T is the temperature in Kelvin.

Note; at RTP (25°C and 1atm) this reduces to:

$$qw = CV \times M \times qA24.5$$

Controlling the humidity of the chambers with accuracy and repeatability is not possible without controlling its temperature.

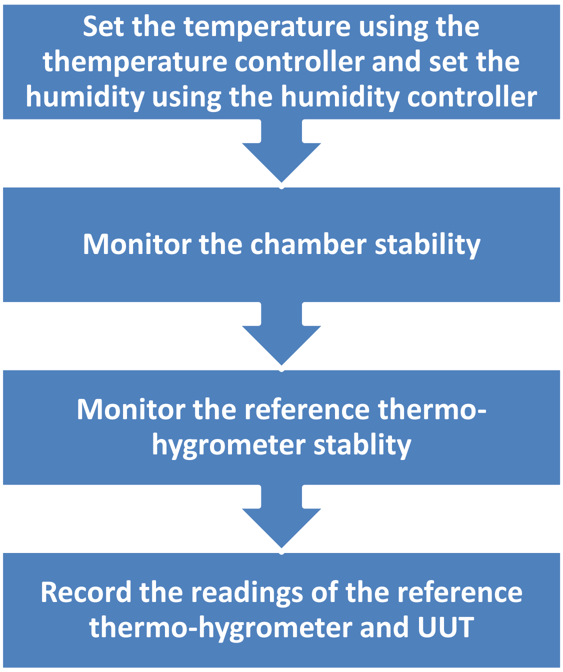


*Figure 2*

The higher in the chamber temperature, it means that the air is capable of handling more moisture at a given temperature. Then, a stable temperature helps ensure a stable humidity level. So refrigeration system is suitable for doing this. The humidity within the chamber can easily decrease using the built in refrigeration system in the chamber attracts moisture in the air, causing it to condense into water, which can then be drained away, then the humidity will decrease until reaches the adjusted setting value of the humidity controller.

Also to increase the chamber humidity we using a controlled ultrasonic humidifier to generate stable water vapor through a small orifice. The water vapor will spread out into the chamber until the humidity reaches the adjusted setting value of the humidity controller, then the humidity controller in turn immediately stops the humidity generator. If the chamber humidity decreased less than the setting value, the humidity controller will restart the ultrasonic generator again until reaching the setting value.

**5. Results and discussion of the characterization of the chamber**

The main objectives of characterization and calibration of unloaded/empty chamber is to determine the uniformity, stability of temperature and humidity within the chamber, temperature/humidity indication error and measurement uncertainty by comparison technique [2]. All measurements were carried out within working zone the chamber according to DIN EN 60068 part 3-5 and DIN 12880 (parts 1 and 2) [3 and 4], through fixing the reference sensors in the corner points and center of working zone the chamber using nine thermo-hygrometer sensors as shown in Fig. 3.

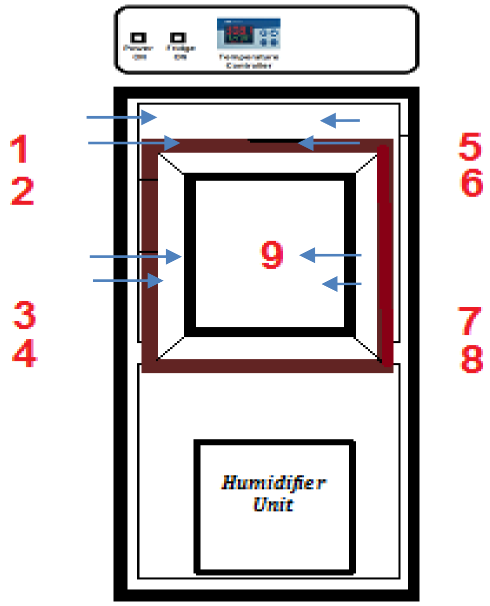


*Figure 3: Set up diagram of reference thermo-hygrometer sensors (from No.1 up to No.9) locations "red numbers" within the working zone of the chamber*

All calibrations of the chamber were carried out in the range from 15 $^{o}$C up to 30 $^{o}$C for temperature and from 40 rh% up to 70 rh% for humidity.

After reference sensors were placed in their positions according to Fig. 3 and ensure closing the chamber doors, we can set the temperature and humidity respectively, with 15 minutes time interval to avoid transient saturation conditions within the chamber.

We can determine the following characteristics for the climatic chamber;

**Temperature/Humidity gradient**

Temperature/Humidity gradient expressed as the difference between the highest and the lowest temperature value of the temperature sensors on different locations within the working space after achieving stability [2].

The maximum value of temperature gradient was found to be 0.4 $^{o}$C at 30 $^{o}$C as shown in table (1). The maximum value of humidity gradient was found to be 1.1 % rh at 70 % rh as shown in table (2).

**Temperature/Humidity fluctuation**

It is the change of the temperature measured at the center of the working space of the chamber after achieving stability [5].

Its maximum temperature fluctuation value was found to be 0.3 $^{o}$C at 30 $^{o}$C, as shown in table (1). The maximum humidity fluctuation value was found to be 0.8 % rh at 70 % rh values as shown in table (2).

**Temperature/Humidity stability**

It is the stability of temperature or relative humidity over a period of time after achieving steady-state conditions. Steady-state conditions are considered to be achieved when systematic variations of temperature or relative humidity are no longer measured [5]. About 30 min of measurements is recorded using a calibrated data logger. All stability measurements are carried out at the center of the working space of the chamber (Location No. 9, see Fig. 3).

The temperature stability was found to be 0.2 °C at 20 °C, as shown in table (3). The humidity stability was found to be 0.4 % rh at 60 % rh values as shown in table (3) and Fig. 4.

**Table 1**: Temperature characterization (gradient & fluctuation) of the chamber

| Setting point, °C | Temperature gradient, °C | Temperature fluctuation, °C |
|---|---|---|
| 15 | 0.3 | 0.2 |
| 20 | 0.3 | 0.3 |
| 30 | 0.4 | 0.3 |

**Table 2**: Humidity characterization (gradient & fluctuation) of the chamber

| Setting point, % rh | Humidity gradient, % rh | Humidity fluctuation, % rh |
|---|---|---|
| 40 | 0.9 | 0.7 |
| 60 | 0.7 | 0.6 |
| 70 | 1.1 | 0.8 |

**Table 3**: Temperature/Humidity stability of the chamber

| Setting point @ | Temperature/Humidity temporal variation |
|---|---|
| 60 %rh | ± 0.9 % rh |
| 20 °C | ± 0.5 °C |

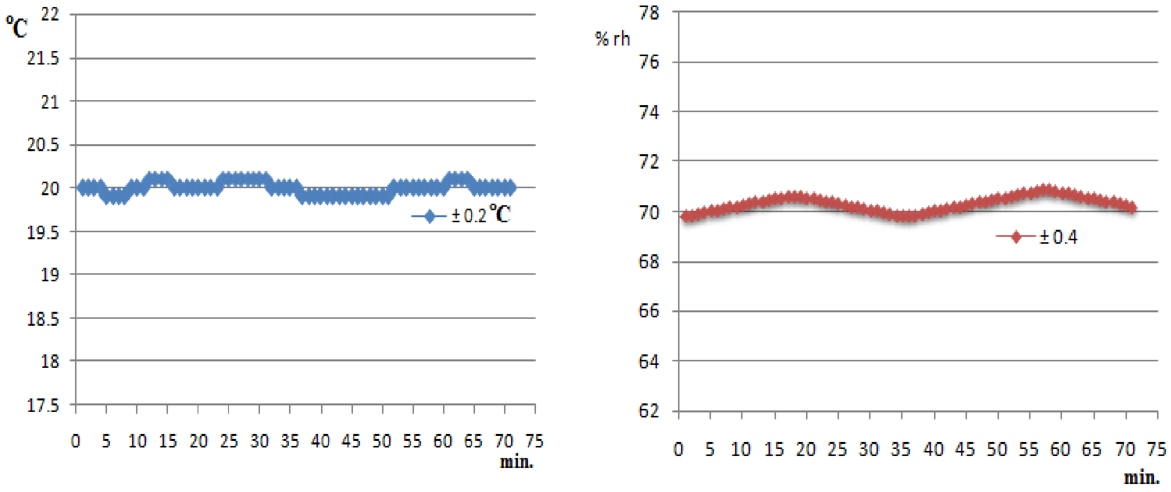


*Figure 4: Temperature and Humidity stability over more than hour within the chamber*

## 6. Temperature/Humidity calibration uncertainty analysis

The uncertainty of measurement includes several components. The temperature and humidity calibration uncertainty budget for this new calibration system is shown in Table 4 and 5, in accordance with JCGM 100:2008, Guide to the Expression of Uncertainty in Measurement (GUM) [6]. Individual components are listed with their estimated standard uncertainties.

The estimation of the uncertainty includes the uncertainty of the used standards which contains; the calibration, the drift and the resolution. But the uncertainty arising from the performance of the chamber includes local homogeneity, instability, loading effect and resolution of the chamber indicator [5].

The measurement uncertainty stated below tables (4, 5) is expanded uncertainty which is obtained from the standard uncertainty by multiplication by the expansion factor k=2 and probability of 95 % confidence level.

**Table 4**: Combination of temperature uncertainties

| | **Uncertainty source** | **Value °C** | **Distribution** | **Divisor** | **Standard uncertainty °C** |
|---|---|---|---|---|---|
| Reference instrument | Calibration | 0.2 | Normal | 2 | 0.1 |
| | Repeatability | 0.15 | Normal | 1 | 0.15 |
| | Temperature effect | 0.1 | rectangular | 1.73 | 0.06 |
| | Drift | 0.1 | Rectangular | 1.73 | 0.06 |
| | Linearity | 0.3 | Rectangular | 1.73 | 0.17 |
| | Resolution | 0.1 | Rectangular | 1.73 | 0.06 |
| Chamber | Temperature gradient | 0.4 | Normal | 1 | 0.4 |
| | Temperature fluctuations | 0.3 | Normal | 1 | 0.3 |
| | Resolution | 0.1 | Rectangular | 1.73 | 0.06 |
| | Instability | 0.5 | Rectangular | 1.73 | 0.29 |
| | Local inhomogeneity | 0.1 | Rectangular | 1.73 | 0.06 |
| Combined Uncertainty = 0.64 °C | | | | | |
| Expanded Uncertainty at C. L. 95% (k=2) = 1.3 °C | | | | | |

**Table 5**: Combination of humidity uncertainties

| | **Uncertainty source** | **Value % rh** | **Distribution** | **Divisor** | **Standard uncertainty** |
|---|---|---|---|---|---|
| Reference Instrument | Instrument Calibration | 0.5 | Normal | 2 | 0.25 |
| | Repeatability | 0.9 | Normal | 1 | 0.9 |
| | Hygrometer drift | 0.1 | Rectangular | 1.73 | 0.06 |
| | Linearity | 0.1 | Rectangular | 1.73 | 0.06 |
| | Resolution of hygrometer | 0.1 | Rectangular | 1.73 | 0.06 |
| Chamber | humidity gradient | 1.1 | Normal | 1 | 1.1 |
| | humidity fluctuations | 0.8 | Normal | 1 | 0.8 |
| | Resolution | 1.0 | Rectangular | 1.73 | 0.58 |
| | instability | 0.9 | rectangular | 1.73 | 0.52 |
| | Local inhomogeneity | 0.3 | Normal | 1 | 0.3 |
| Combined Uncertainty = 1.85 % rh | | | | | |
| Expanded Uncertainty at C. L. 95% (k=2) = 3.7 % rh | | | | | |

## Conclusion

A simple low cost system has been built for humidity/temperature calibration with working temperature range from 5 °C to 50 °C and from 50 % rh to 98 % rh for humidity.

The characterization results have shown that the gradient within chamber is 0.4 °C for temperature and 1.1 % rh humidity in the working range.

This system achieved a good accuracies and stability for humidity/temperature calibration. The results have shown also that the system calibration capability is 0.8 °C for temperature and 3.7 % rh for humidity in the working range.

Further on the basis of cost and simplicity of construction is a very important advantage for this system.

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