Design, construction and implementation of relative humidity and temperature climatic chamber for metrology laboratory

Johan S Malpica Gutierrez, Ismael A Fernández Peña, Fernando Martínez Santa
Facultad Tecnológica, Universidad Distrital Francisco José de Caldas, Bogotá, Colombia
E-mail: jsmalpicag@correo.udistrital.edu.co,iafernadezp@correo.udistrital.edu.co, fmartinezs@udistrital.edu.co

Abstract. For the calibration of thermohygrometers it is necessary to have a means of generating temperature and relative humidity for this reason in this development we will build a climatic chamber which will generate and control these two magnitudes. For the generation of temperature a thermoresistance was used and the decrease of relative humidity was done through a silica gel trap through which the air inside the chamber is recirculated with the use of a vacuum pump. On the other hand, an ultrasonic humidity generator also known as fogger was used to increase the relative humidity. For the construction of the chamber, acrylic was used as the main material, since it is translucent and facilitates the visualization of the thermohygrometers' indications. For the control of the process variables such as temperature and relative humidity, an Arduino card was used, which through PWM pulse width modulation, the control was performed achieving a variation of 0.3 °C and 2 %RH, which will be evaluated by an accredited laboratory in the characterization of isothermal media certified by ONAC, since it is in this way that the inhomogeneity, stability and thermal load of the medium, components that affect the uncertainty of the instruments under calibration, are evaluated. It should be remembered that this development was carried out in order to create an air medium with which temperature and relative humidity measuring instruments can be calibrated in the metrology laboratory VALIDACIONES Y METROLOGÍA LM S.A.S., since it is in the process of growth and one of its main objectives is to be accredited in the magnitudes of temperature and relative humidity before the accreditation body in Colombia (ONAC), which is the entity that will finally give the technical approval to release the chamber and put it into operation.

1. Introduction

The laboratory VALIDACIONES Y METROLOGÍA L&M S.A.S. is a national laboratory (Colombia) with more than six years of experience in calibration and validation of measuring instruments. Based on the growth and development of the laboratory it is necessary the creation and implementation of an air-conditioned chamber for the calibration process of thermohygrometers and meters of environmental conditions.

This article describes the design and construction of a prototype climatic chamber that was carried out in order to generate and control environmental conditions in temperature and rela-
tive humidity over a certain operating range to perform calibration tests to thermometers and hygrometers, in compliance with the current national and international technical requirements contained in the NTC-ISO/IEC 17025 standard, which establishes the standards for the management of equipment and tests in metrology laboratories. [1][2][3].

This development is based on the following objectives to achieve the Accreditation before the national accreditation body of Colombia ONAC in the calibration of measuring instruments in the magnitudes of ambient temperature and relative humidity, obtaining a measurement and calibration capacity (CMC) competitive in the market[4].

Based on the design and construction of the climatic chamber, an evaluation of its performance will be carried out based on a characterization that allows determining the behavior of the variables to be controlled according to the measurement intervals for the equipment to be calibrated, establishing the operating ranges for temperature (25 °C to 50 °C) and relative humidity (10 %HR a 90%HR).

2. Methodology

The following flow chart describes the development process of the climatic chamber.

![Figure 1. Development process flow chart climatic chamber.](image)
The development of this work is presented as follows. In the first stage, the development and construction of the climatic chamber is carried out, defining the basic concepts of functioning and operation. In the second stage, the control system is described by means of a block diagram to model. This control of the equipment maintains the Set Points (SP) initially established in the chamber for the ambient temperature and relative humidity. In the last stage, the chamber operation tests will be carried out in order to determine the contribution to the uncertainty that this will provide to the instruments under calibration.

3. Development and construction of the climatic chamber

he main material used for the construction of the stability chamber was acrylic since it is a material that allows to maintain the conditions due to its thermal insulating property, besides it is also possible to visualize the indication and behavior of the instruments under calibration. The design is based on a rectangular structure of dimensions 40 cm x 26 cm x 26 cm, which has a door on the right side for the entry and exit of the instruments under calibration, this same one has a gasket that isolates the internal environmental conditions from the environmental conditions of the laboratory, additionally two (2) acrylic boxes were built, which are external to the stability chamber.

The first box houses the power and control circuit, which will be explained in the Control system section. The second box houses the humidifier or fogger whose function is to change the water in the reservoir from a liquid to a gaseous state, generating humidity in the chamber according to the signal received from the controller[5]. To carry out the dehumidification process in the chamber, a vacuum pump was installed which removes the humid air from the chamber by passing it through a trap with a CaSO4 desiccant filter and the dry air is recirculated back into the chamber; it should be noted that the fittings and hoses through which the air circulates are totally airtight [6] [7][8].

The temperature regulation system is built by means of a resistor which receives the control signal and is activated generating an increase in temperature [9]. To reduce the temperature, the heating element is deactivated and, by recirculation of air into the chamber, the temperature is lowered.

4. Control system

The control system was made by programming in C language using free Arduino software and UNO motherboard as embedded system. The variables to be controlled will be the ambient temperature and relative humidity of the air. The program designed allows the control to react to changes in environmental conditions in the chamber and quickly compensates the values of the variables according to values preseted by activating the different actuators. The control to be applied on these variables must take into account the environmental conditions and the different thermal loads that can be generated, added or extracted from the interior of the space to be controlled.[10].

The actuators used in the process plant to control environmental conditions are:

• For heating: 110 VAC thermo resistance at 3 000 Watts of forced convection.
• For humidification: 24 VDC ultrasonic fogger with natural convection.
• For Dehumidification: 110 VAC air recirculation vacuum pump for desiccant CaSO4.
Figure 2. Stability chamber final result.

Stability and uniformity conditions inside the chamber are obtained by forced convection using four (4) fans strategically arranged at the corners and in opposite directions to each other.

Figure 3. Forced convection air flow representation.

The control system established for the resistance thermometer is by PWM pulse width modulation ensuring low overshoot and steady state error of ±0.1 °C approximately, for the Fogger and pump controls are ON / OFF due to the same nature of the actuators, however as a measure of protection for the actuators of the chamber, the control system enters Standby mode when conditions are in a range set around the Set established, ±0.3 °C in temperature and ±0.7 % hr for relative humidity. The control to apply on these variables must take into account the environmental conditions and the different thermal loads that can be generated, added or extracted from inside the space to be controlled.

The block diagram of the closed-loop control circuit is illustrated below.
5. Functional testings

After assembling the climatic chamber, a series of functional tests were performed in order to verify if the environment is suitable for the calibration of thermometers and hygrometers, not without first remembering that it is a forced convection air environment under conditions that must be taken into account when qualifying or characterizing the equipment.

Figure 5 shows the relative humidity indication vs. time when the chamber is programmed at a set point of 70 %RH, where the stabilization phase of the relative humidity inside the chamber and its behavior in the stable phase can be observed.
Figure 6 shows the temperature vs. time indication when the chamber is programmed at a Set point of 40 °C, where the temperature stabilization phase inside the chamber and its behavior in the stable phase can be observed.

![Temperature graph](image)

Figure 6. Temperature graph

6. Characterization of the environment

Characterization of the medium is performed in order to check the temperature deltas throughout its useful volume [11]. The temperature delta are determined from the determination of the temporal instability of the chamber, the spatial inhomogeneity, the thermal load and, if considered, the possible effect of radiation emitted by the chamber walls, but since the chamber is made of acrylic, this variable is considered negligible. Evaluating all these variables, the contribution to the uncertainty provided by the climatic chamber is determined [12].

The measured values of ambient temperature and relative humidity are the average of 10 data at each position, the ambient temperatures shown are determined using a thermometer with low emissivity.

The characterization of the equipment is carried out taking into account the useful volume of the equipment, since the distribution of the location of the measurement sensors in the X, Y and Z axes depends on it.
7. Evaluation of uncertainty

The uncertainty of measurement is known as a non-negative parameter that characterizes the dispersion of the values attributed to a measurand, from the information that is used, in other words, it is the degree of "doubt" that is had on the result of any measurement, the components of uncertainty that the camera contributes to the result of the calibration of thermohygrometers are those of stability and uniformity and this design seeks that these values are the lowest possible within reason and with the support of an accredited laboratory in characterization of isothermal media [13].

The contribution for medium uniformity corresponds to the uniformity value of the environmental conditions chamber divided into $\sqrt{3}$.

$$U_{unf} = \frac{Uniformity}{\sqrt{3}}$$  (1)

The contribution for stability of the medium corresponds to the uniformity value of the environmental conditions chamber divided into $\sqrt{12}$.

$$U_{unf} = \frac{Uniformity}{\sqrt{12}}$$  (2)

![Table](image)

**Figure 7.** Uncertainty components associated with calibration of thermohygrometers

During the calibration process of thermohygrometers other uncertainty components are taken into account as detailed below, finally the combination of all these components multiplied by the respective coverage factor will estimate the expanded uncertainty for a confidence level of
approximately %.95 [14][15].

A calibration may be expressed by a statement, a calibration function, a calibration diagram, a calibration curve or a calibration table. In some cases, it may consist of an additive or multiplicative correction of the indication with its corresponding uncertainty [16][17][18].

8. Results

To evaluate the results of the development of the climatic chamber, a calibration was requested by a laboratory accredited by the national accreditation body ONAC, and based on the results obtained in the characterization, the effectiveness of the development is evaluated.

From the calibration performed by the metrology laboratory SET Y GAD S.A.S. with accreditation code before the national accreditation body of Colombia ONAC 18 -LAC-004, the calibration certificate number HM0310-21 was issued, in which the following results were obtained.

![Figure 8. Location of sensors during characterization](image)

| Evaluated Parameter | Design | Result of characterization | Acceptance requirements |
|---------------------|--------|---------------------------|------------------------|
| Stability           | 0.5 %HR| 0,194 %HR                 | Meets                  |
| Uniformity          | 2.5 %HR| 1.98 %HR                  | Meets                  |
| Thermal load        | 1 %HR  | 0.52 %HR                  | Meets                  |

In conclusion, when analyzing the stability, uniformity and thermal load data, it can be seen that the design conditions were exceeded, since in terms of temperature uniformity a value of 0.5 °C was expected and with the characterization process a value of 04030 °C was obtained, in the same way, values lower than those expected in the design stage of the climatic chamber for the calibration of thermohygrometers were obtained.
Table 2. Design conditions vs real conditions in the magnitude temperature.

| Evaluated Parameter | Design Result of characterization | Acceptance requirements |
|---------------------|----------------------------------|-------------------------|
| Stability           | 0.3 °C 0.168 °C                  | Meets                   |
| Uniformity          | 0.5 °C 0.4030 °C                 | Meets                   |
| Thermal load        | 0.1 °C 0.008 °C                  | Meets                   |

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References
[1] Muñoz Guatibonza J A 2018 Diseño de una cámara climatizada, automatizada, con manejo de información por telemetría y condiciones operativas controladas para pruebas de equipos y materiales B.S. thesis Fundación Universidad de América
[2] Arango O E A 2018 Diseño e Implementación de un prototipo de control de humedad relativa para una cámara existente en el laboratorio de metrología de variables eléctricas de la Ph.D. thesis Universidad Tecnológica de Pereira
[3] Kalibrierdienst D 2004 Guideline DKD-R 5-7 Calibration of climatic chambers Deutscher Kalibrierdienst (DKD) Deutscher Kalibrierdienst DKD 7th ed
[4] Tamani B V 2007 Obtención de modelos de procesos mediante métodos de identificación recursiva UNMSM-Facultad de Ingeniería Electrónica y Eléctrica de la Universidad Nacional Mayor de San Marcos, Lima, Perú 27–35
[5] Fan K C, Wang H and Liu Y C 2008 Development of a constant temperature environment chamber with high stability vol 594 (Trans Tech Publ) pp 78–83
[6] Mahmoud E E D 2009 Realization of relative humidity scale from 10% to 98% at 25 °C Mapan 24 241–245
[7] Lee S W, Choi B I, Woo S B, Kim J C and Kim Y G 2019 Development of a low-temperature low-pressure humidity chamber for calibration of radiosonde humidity sensors BIPM & IOP Publishing Ltd 56
[8] Cram L 1956 Journal of scientific instruments 33 273
[9] Van Geel J, Bosma R, Van Wensveen J and Peruzzi A 2015 Thermistors used in climatic chamber at high temperature and humidity International Journal of Thermophysics 36 569–576
[10] Cardona Gil J A, Pazos Urrea J P et al. 2014 Cámara de ambiente controlado para la supervivencia de plantas e insectos Universidad Pontificia Bolivariana
[11] Davis J B 2009 Handbook of Stability Testing in Pharmaceutical Development (Springer) pp 285–302
[12] WONG G and HERMAN LAM P 2005 Qualification of Environmental Chambers Analytical Method Validation and Instrument Performance Verification 243
[13] Aranda N G, Rocio N M, García Skabar J et al. 2021 Optimización de los métodos y procedimientos de calibración de termohigrómetros en el Centro Regional de Instrumentos de Buenos Aires Servicio Meteorológico Nacional Dirección Nacional de Infraestructura
[14] FENOTTI F and VASTY D 2019 19th International Congress of Metrology (CIM2019) (EDP Sciences) p 18003
[15] Dona M I 2010 University” Politehnica” of Bucharest Scientific Bulletin, Series C: Electrical Engineering 72 197–210
[16] Vendt P D R and Leito I 2014 2014 A method for thermal ambient tests of space technology equipment in a thermal chamber-development and validation Master’s thesis
[17] Esquivel A E 2015 Metrología y sus aplicaciones 2nd ed (Larousse, grupo editorial patria)
[18] Kumar S P, Shanmugasundaram N and Ganesh E 2018 International Journal of Engineering & Technology 7 307–310