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THE METHOD FOR STABILISATION OF TEMPERATURE AND HUMIDITY IN VOC CHAMBERS

Key words

VOC, humidity, temperature, fuzzy logic.

Abstract

This paper presents selected issues of the design of precise control devices for the characteristics of the process environment in the VOC (Volatile Organic Compounds) chambers, in which non-standard validation tests are performed. The main parameters defining the environmental conditions are temperature and humidity. Particular attention was paid to the elimination of pollution generating sources in the background of the chamber. The module designed to control the temperature and humidity is presented. The results of the recording of temperature and humidity in several-month-long test cycles are presented. The developed modules have been used in chambers for testing the emissions of volatile organic compounds and formaldehyde.

Introduction

In the process environment (Fig. 1), usually implemented by the validation chamber, in which the test piece is placed, we distinguish an environmental parameter maintenance subsystem, a subsystem to generate excitations on the test object, and a subsystem for control and measuring environmental parameters (climate) and the reaction to the test object to excitations. The division of these systems depends on the test procedure, e.g., the force exerted on the test object in the chamber either may be the environmental parameter or generated excitation.

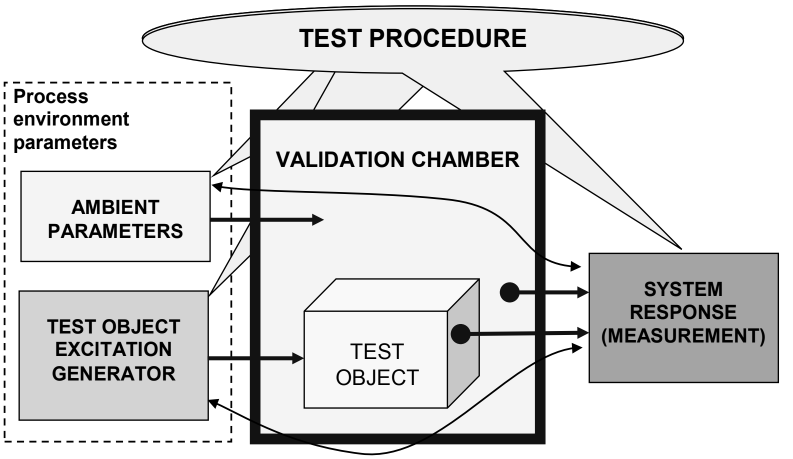

Fig. 1. Validation chamber as a system with controlled characteristics of process environment

Within the task "Specialized equipment for validation testing with controlled characteristics of the process" realised within Strategic Programme of the chambers for testing VOC emissions and carbonation of concrete were selected as examples. The VOC chamber can also be used to test formaldehyde emission with a chamber method.

The idea of VOC emissions test is as follows:

- The chamber in which the sample is placed is made of glass or stainless steel. The seals are Teflon. The study of emissions of volatile organic compounds is carried out at a temperature 23°C±0.5°C and a relative humidity 45% RH±3.0% for the European standards, and at 25°C±1.0°C and a humidity of 50% RH±4.0% for the United States requirements.
- The chamber pressure is maintained at 1000–2000 Pa.
- A service unit supplies air at a suitable temperature, humidity, and cleanliness.
- The analysis of samples is carried out using a chromatograph.

The paper discusses the temperature and humidity control for VOC chambers, in which, because of the method of the test, there is no need to lower the humidity and temperature.

As a result of the analysis of standards [2] to [6], it was assumed that the construction of the chamber should be as follows:

- Air supply – air intake with filter: Air intake is from the outside, from a zero air generator, or from a lubricant-free compressor.
- Service unit: It functions to ensure the temperature, humidity, and the mass volume control of air flow (in the standard [2] conditioning system, airflow regulator).
- The VOC chamber: It consists in an internal fan with a motor located on the outside of the chamber to ensure the airflow rate around the sample in the range of 0.1–0.3 m/s.
- Sample acquisition system air from the chamber.
- A data acquisition system: This is a standard system for monitoring temperature and humidity.

A block diagram of the test chamber for VOC emissions is shown in (Fig. 2).

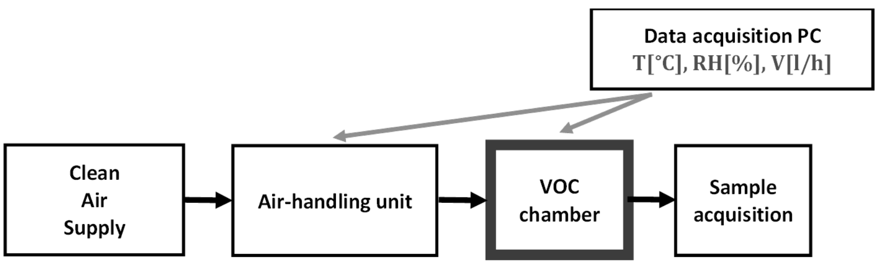

Fig. 2. Schematic diagram of a chamber for testing the VOC emissions

Since the chambers are made of glass or stainless steel and have no insulation, it is required that the VOC chamber is placed in an air-conditioned room [1]. Since the standard air conditioning does not provide a good stabilisation of the temperature in the room, the use of reheated air introduced into the chamber is required.

An important problem is the purity of the background of the chamber, tested by chromatographic methods, which should be <20 g/m^3, the total concentration of volatile organic compounds (TVOC), and the concentration of a single intentional VOC should be <2 μg/m^3.

1. Air humidity control module

The standard PN-EN 717-1:2004 [2] shows a sample device for RH stabilisation of the controlled air flow with a relative humidity 45% (Fig. 3).

According to the standard, the idea of preparation of air of the desired relative humidity is mixing dry air stream, which is the upper tract, with the air humidified in the washers, which is the lower tract [2]. This method of conditioning the relative humidity of air (gas) is used in other applications developed at ITeE-PIB. After analysis, the construction of an air-handling unit was proposed according to the diagram (Fig. 4). What is new is the use of two mass flow regulators controlled by an electric signal of 4–20 mA and an automatic water filling system.

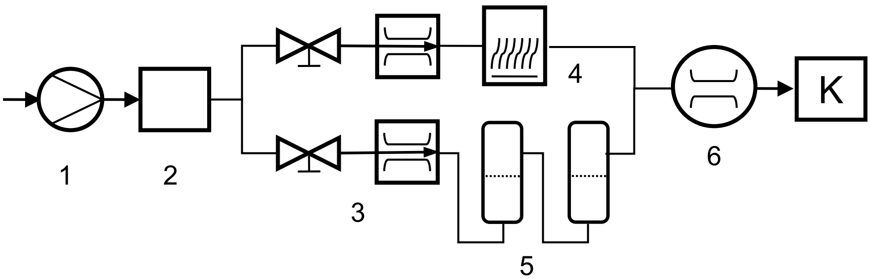

Fig. 3. Sample structure of an air preparation system according to PN-EN 717-1:2004 [2]: 1) Gas pump, 2) Charcoal filter, 3) Flow meter and flow control for air, 4) Silica gel filter, 5) Water washer (humidification), 6) Flow control or gas-meter; K) Validation chamber

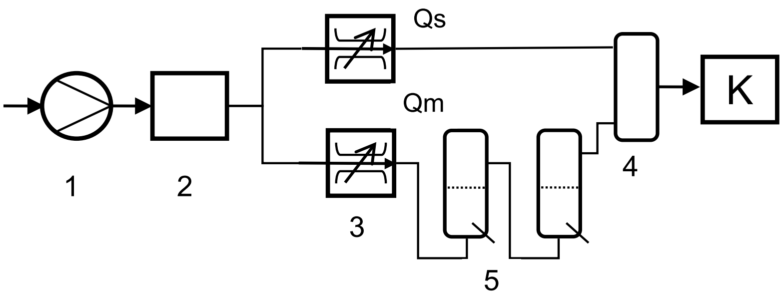

Fig. 4. The structure of the service unit with two flow regulators: 1) Lubricant-free compressor, 2) Air filters, 3) Air flow regulator, 4) Mixing tank with heaters, 5) Washers with automated water filling system, 6) Regulated dumping valve, F) Air filters, K) Validation chamber

Given air flow Q_Z [l/h] calculated according to the standard is divided for two flow regulators – dry air tract Q_s and moist air tract Q_m according to the following equations:

$$Q_Z = Q_s + Q_m \quad Q_s = k_s \cdot Q_Z \text{ and } Q_m = k_m \cdot Q_Z \tag{1}$$

where

$$k_s + k_m = 1 \text{ and } k_s, k_m \geq 0.02 \quad Q_s \geq Q_{min} \text{ and } Q_m \geq Q_{min} \tag{2}$$

Q_{min} is a minimal value possible to obtain and resulting from the "regulation depth" of the regulator. For the applied mass flow regulators, the regulation depth is 50:1. So when the regulator with a maximum flow of 250 [l/h] is used, the minimal flow is 5 [l/h] for dry air and moist air, so the total minimal flow is 10 [l/h]. Then, $k_s = k_m = 0.5$. The user sets the required value of air humidity and the PLC based measurement-control system calculates and regulates proper coefficients k_s and k_m. Fig. 5 shows the developed air preparation system [7].

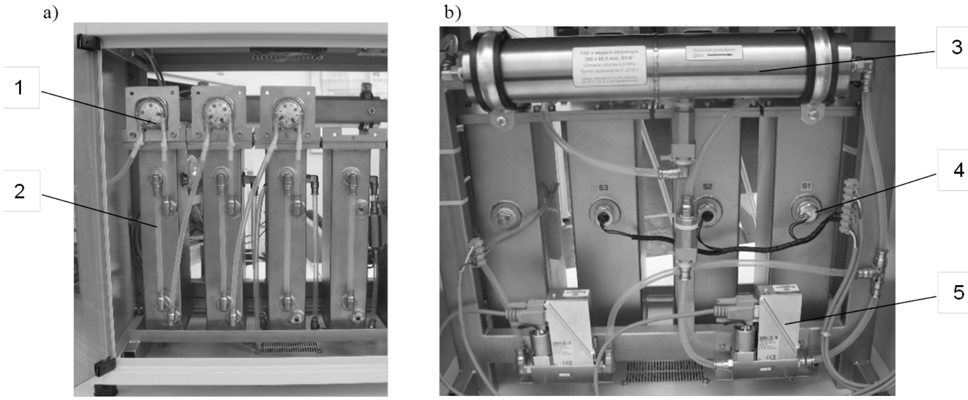

Fig. 5. Air preparation unit with steel washers with automated water filling and two flow regulators: a) washer with peristaltic pumps – front, b) mass flow meters – back of the unit; 1) peristaltic pump, 2) Washer units with level gauges, 3) Carbon filter, 4) The water level sensor, 5) Air mass flow regulator

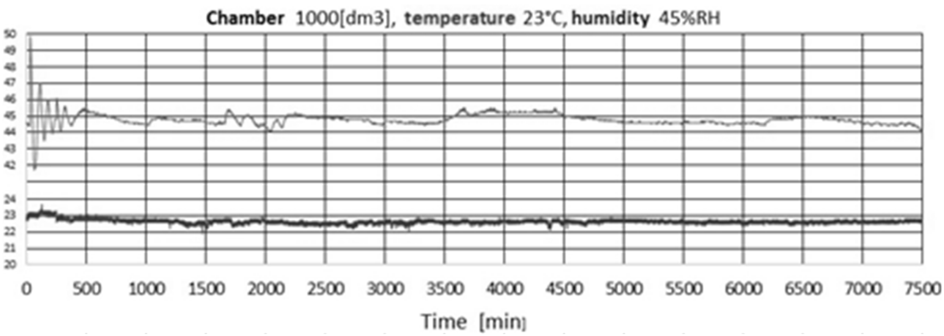

Fig. 6. Long-term test of the glass chamber of volume of 1000 dm^3 – without heater inside of the chamber and with two mass flow regulators according to diagram (Fig. 4). Record time approx. 125 days, sampling period 5 seconds

The developed service unit has been subjected to long-term tests. The results of the regulation of temperature and humidity are shown in (Fig. 6) [7]. For the tests, a chamber with a volume of 1000 dm^3 was selected, which is more difficult to stabilise due to its size. At the beginning of the test, the experiments with the airflow regulator were conducted, including starting and stopping the airflow. Later, the airflow was set at 1195 [l/h], which allows the exchange of air in the chamber within approx. 1 hour.

The developed service unit has also been tested for air purity. The chromatograms of "zero" air samples taken from the cylinder, zero air generator, and after passing through the air handling system were compared. The results are shown in (Fig. 7). All samples were collected under a pressure of about 0.01 bar, at the airflow of 200 [l/h]. The amount of air was approximately 10 [l] (18 l/h for 30 min). Each sample was acquired 2 times on two different Tanax TA absorption tubes, and the results are consistent.

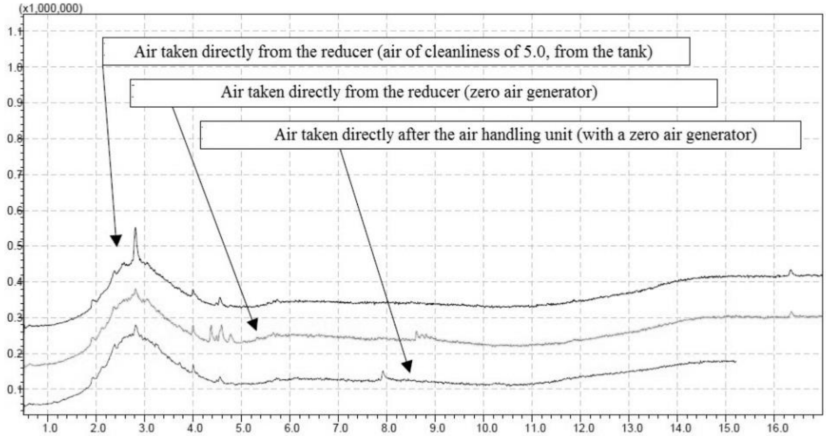

Fig. 7. Chromatographic tests of the zero air from the container, from the zero air generator and after passing through the air preparation system

The tests documented very good air quality obtained from an air-handling unit.

2. Air temperature control module

As mentioned in the introduction, due to the use of glass and metal chambers without external insulation, the chambers were placed in an air-conditioned room. Therefore, the temperature control system only regulates the air temperature within the chamber to a small extent, i.e. a few degrees and a few percent relative humidity.

Air density is dependent on pressure, temperature and composition, for example, the density of dry air, at atmospheric pressure at sea level at a temperature of 20°C is about $\rho = 1.2$ kg/m^3. The specific heat of the air is c = 1005 J/kg/K. Therefore, to heat V = 1 m^3 of air (the volume of one of the typical chambers) by Δt = 1 K the energy needed is

$$Q = \rho*V*c*\Delta t = 1206 \text{ J} \quad (3)$$

With the heater power of P = 24 W, the required time is approx. Q/P≈50 s (at 100% efficiency and in the absence of airflow through the chamber). This is an acceptable time, given the time of tests in VOC chambers (up to several hundred hours).

The method for heating the chamber uses an external heater with a temperature sensor installed in the bottom of the chamber and the external heaters of mixing tank (Fig. 4).

3. Algorithms for air temperature and humidity control

The control and measurement system for the air-handling unit is realised by means of a PLC equipped with touch screen HMI operator panel. To adjust the humidity and temperature, the fuzzy controller is used with the consequent fuzzy singleton according to the model used in the PLC controllers [8]. The presented algorithm and its implementation is the author's solution, since the applied PLC does not provide the implemented fuzzy controller. For analogue signals measured (e.g. humidity, temperature) and calculated (e.g. the rate of change), a method was designed for determining the scope of these signals using the deltas and the lower and upper limits. δ – is used to determine the parameters of the desired range of stabilisation, Δ – defines the scope of the need to change the control-stabilised variable. The developed structure of limit values is helpful for determining fuzzy sets (Fig. 8), boundary fuzzy sets are of the type Z and S, while the middle are of the Λ type. Similarly, fuzzy sets are designed for temperature; we substitute RH with T. Fuzzy sets that are defined with the parametrised conversion macros. The calculations are simplified with a floating-point arithmetic implemented in the controller.

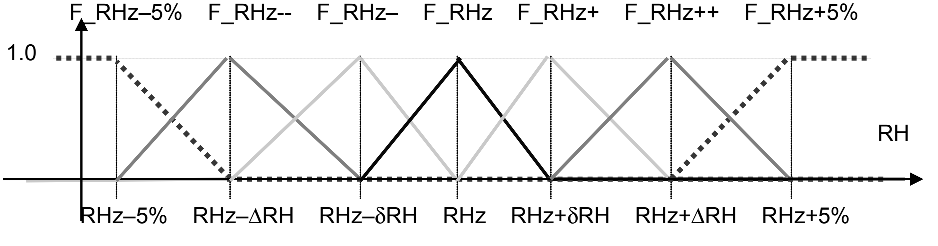

Fig. 8. Definition of fuzzy sets for air humidity

The ratio of airflow is adjusted immediately, and it takes several tens of milliseconds to settle. In contrast, the effect of changes in humidity after changing of the flow ratio is deferred over time. Therefore, the process of adjusting the humidity has long time constants and long delays. To control it, additional mechanisms were introduced to facilitate the implementation of control as follows:

- Generating of a flow control at a control period has the time resulting from the time constants of thermohygrometer and time constants of the system. This is the time, followed by the correction coefficients $k_s + k_m = 1$ in the discussed method for adjusting the humidity.
- Information about the direction of changes in humidity (RH↓, RH=, RH↑) are updated at the control period.

Sample temperature and humidity rules have the following forms:

IF RH **is** F_RHz-- **and** RH↑ **THEN** Flow($k_s := k_s + 0.005$) (5)

IF RH **is** F_RHz **and** RH= **THEN** Flow($k_s := k_s$) (6)

IF T **is** F_Tz-- **THEN** Heater=PWM%80 (7)

IF T **is** F_Tz+ **THEN** Heater=PWM%off (8)

Since the temperature adjustment process is slow, there is no need to take into account the rate of change in temperature, since the VOC chamber is not thermally insulated, and the temperature in the air-conditioned room is near the set-point temperature. Long-term tests of the regulation confirm the assumed concept of the temperature and humidity controller (Fig. 6).

Summary

The module for humidity and temperature regulation developed by the author of this article is intended to construct specialised chambers for testing VOC emissions. This method, with two mass flow controllers to regulate the humidity, has proven itself in practice and ensures the desired air quality. Presently, 21 of VOC chambers in different versions have been constructed.

The author's control algorithm for humidity and temperature of the object in which there are long delays and large time constants was developed. The thermohygrometer reaction time is 30 seconds. The algorithm is independent of the size of the VOC chamber, and the same is applied to the chamber with a capacity of 225 dm^3 and 1000 dm^3. Long-term tests confirm the good stabilization of the temperature and humidity in the VOC chamber.

The measurement and control software takes the form of the distinguished procedures with separate memory spaces, which can be used for software development for other chambers. In case of VOC chambers, there is no need for intensive drying of the chamber space.

The concept of measurement and control system in the form of an open distributed system allows flexible configuration of VOC chambers and their modifications in the future.

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Metoda stabilizacji temperatury i wilgotności w komorach VOC

Słowa kluczowe

VOC, wilgotność, temperatura, logika rozmyta.

Streszczenie

W artykule przedstawiono wybrane zagadnienia projektowania urządzeń do precyzyjnego sterowania charakterystykami środowiska procesowego w komorach VOC (*Volatile Organic Compounds*), w których prowadzone są niestandardowe badania atestacyjne. Głównymi parametrami określającymi warunki środowiska jest temperatura i wilgotność. Szczególną uwagę zwrócono na eliminację źródeł generowania zanieczyszczeń w tle komory. Zaprezentowano opracowany moduł do regulacji temperatury i wilgotności. Przedstawiono wyniki rejestracji temperatury i wilgotności w kilkumiesięcznych cyklach badawczych. Opracowane moduły zostały zastosowane w komorach do badania emisji lotnych związków organicznych oraz formaldehydu.