Automatic humidification system to support the assessment of food drying processes

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Abstract. This work shows the main features of an automatic humidification system to provide drying air that match environmental conditions of different climate zones. This conditioned air is then used to assess the drying process of different agro-industrial products at the Automation and Control for Agro-industrial Processes Laboratory of the Pontifical Bolivarian University of Bucaramanga, Colombia. The automatic system allows creating and improving control strategies to supply drying air under specified conditions of temperature and humidity. The development of automatic routines to control and acquire real time data was made possible by the use of robust control systems and suitable instrumentation. The signals are read and directed to a controller memory where they are scaled and transferred to a memory unit. Using the IP address is possible to access data to perform supervision tasks. One important characteristic of this automatic system is the Dynamic Data Exchange Server (DDE) to allow direct communication between the control unit and the computer used to build experimental curves.

1. Introduction

Food drying is an industrial process used to reduce water activity in products allowing its conservation, storage stability and transportation [1]. However, the development of new drying techniques or the evaluation of new dried products requires a very careful approach. All processes involved even in simpler dryers are highly non-linear and its scale-up is generally very difficult, requiring experimentation at laboratory and pilot scales coupled with the experience of the researcher [2]. Hence, a research approach involves basic models that are validated using experimental outcomes. Most of models require an understanding of the typical product behavior during drying, and most of this information can be drawn from the so-called drying curves that presents the mass decrement versus time at stable drying conditions. Every food has a representative drying curve related to drying air velocity, temperature and pressure that reflects how removal of water is affected during the process; using the slope of these curves, is possible to obtain the drying rate curve, which is in turn very important to make assumptions for the construction of mechanics of dried materials [3,4]. Foods in particular presents, after a period of constant rate drying, a period characterized by a deceleration of water removal. The rate-controlling factors in this period are complex, depending upon diffusion through the food, and upon the changing energy-binding pattern of the water molecules. There is little theoretical information available for drying of foods in this particular region and experimental drying curves are the only adequate approach.

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The drying curves are based on the mass reduction with time when the product is dehydrated in a laboratory dryer. Most of the experimental devices used are composed by a propeller fan, an electric heater, a scale and a humidifier. The temperature and the moisture content of the drying air is keep stable through heating and a supply of fresh air or steam, or using saturated air.

One of the most important parameters in drying is humidity, but unlike temperature and velocity of air, it is quite difficult to measure it and control it. In earlier experiments the air used had a low humidity or was taken from the environment. This is a very simple way to set up experiments, but it has a poor reproducibility because the humidity depends on ambient conditions [5]. Nonetheless, it is possible to use air with known humidity. From one hand, air is equilibrated with a saturated salt solution at a constant temperature, providing a known humidity air [6]. Its drawbacks are the long time required to reach equilibrium and the difficulty to produce large amounts of conditioned air. Another procedure is known as the two-flow method [7]. In this instance, a stream of gas is divided into two parts, one is saturated with water at a certain temperature and the other is a dry gas; both streams are then mixed producing the desired conditioned air. Its most important drawback is the flow rate measurement and requires an efficient saturation process along with good temperature control of the air coming out the saturator. Similarly, in the two temperature method a stream of air is saturated with air at a given temperature and then the last is raised. Here, accuracy depends on the temperature measurement and the saturator efficiency. Finally, in the two-pressure method a stream of air at a high pressure is saturated with water at a given temperature and then reduced to a lower pressure. This method requires accurate measurement of the pressure and temperature.

As a common characteristic, all precedent methods require the measurement of at least one physical variable and their accuracy depends on how well the specific variable is measured. Besides, they can only produce limited amounts of treated air [8]. Consequently, most of the experimental units used for investigation of drying processes have a reduced size and only small samples of the product of interest can be evaluated. The experimental apparatus normally consist of a drying device in which the product sample is exposed to a controlled air flow (Temperature, humidity and speed), and both test cross section and samples zone are quite small [9,10].

2. Description of the automatic humidification system

The automatic humidification system is used to control humidity and temperature of air in an experimental facility. This facility has been developed at the Automation and Control for Agro-industrial Processes Laboratory of the Pontifical Bolivarian University, looking forward to emulate ambient air of different climatic zones and to obtain the drying curves of a wide range of agro-industrial products. Figure 1 illustrates the main elements of the test unit where the automatic humidification system was set-up. It consists of a ring of convective drying where a dryer or a drying box can be placed to evaluate different products. The unit has been instrumented with several temperature, humidity and velocity sensors for air monitoring, and strain gages to measure the weight of the product being dried.

The experimental apparatus has to produce an important quantity of conditioned air because its major purpose is to evaluate the performance of prototype dryers. In this unit, temperature and humidity of the air are controlled in real time. From one hand, it features an air conditioning unit that reduces temperature and humidity of ambient air depending on the conditions of the convective stream to be use in a particular experiment. Then, the amount the air required in the dryer is extracted by a blower and passed through the Heating Humidification Unit (H₂U), which finally delivers the air to the Dryer.

Figure 2 illustrates the main features of the H₂U. It has temperature and humidity sensors, a set of high pressure water nozzles and a set of electric heaters.
Sensors and actuators are linked to a control unit that is responsible for maintaining the required conditions of the air flowing to the dryer. A Programing Logic Control (PLC) device was used along with four variable frequency drives and two slave modules for in/out (IO) signals. Figure 3 shows an outline of the control network put in place and its components. The development of automatic routines to control and acquire real time data was made possible by the use of robust control systems and suitable instrumentation. The signals are read and directed to the controller memory where they are scaled and transferred to a memory unit. Using the IP address is possible to access data to perform supervision tasks.
One important characteristic of this automatic system is the Dynamic Data Exchange Server (DDE) that allows direct communication between the control unit and the computer used to build the experimental curves. Industrial devices like PLC have limited local memory, making necessary to manage and save huge amounts of data for off-line analysis. Notwithstanding that industrial systems commonly use OPC (Object Linking and Embedding for Process Control) as communication protocol, in order to link devices from different brands, it is necessity to acquire specific commercial software applications. This represents additional costs to implement supervisory control and data acquisition systems. On the contrary, DDE is a standard feature in computers running Microsoft Windows, which allows easy access to data from multiple applications. Additionally, the experimental facility has actively involved the concept of Totally Integrated Automation (TIA) to combine different automation architectures, with the derived advantages outlined in the specialized literature [11].

![Control network](image)

**Figure 3.** Control network.

3. Results
When the experimental facility is used to emulate a specific climate zone, the results show great agreement with the real air conditions. The equipment is able to produce air with the same average temperature and humidity of Colombian cities with extreme environments. Figure 4 shows a Humidity and Temperature diagram when the automatic system is controlling the variables of interest using an on/off strategy. In this instance, the temperature of the air reaches a relative humidity of 80%, while the temperature of the air leaving the H2U unit remains at about 35°C. After this point, the unit stops humidification and the air inlet temperature is no longer controlled in the conditioning ring.
Figure 4. Humidity and Temperature of air vs time. On/off control.

Figure 5 shows another example of the system operating strategy to reach air at 50°C and of 43% relative humidity, when air temperature is high and humidity is low at the initial condition. In this instance, it was implemented a step on/off fuzzy control strategy.

Figure 5. Humidity and Temperature diagram of air vs time. Step on/off fuzzy control.

When a prototype rotary dryer was used to build the drying curves of coffee beans and cassava, the automatic system allowed to obtain the weight of the dryer load in real time using precision strain gages. Figure 6 shows the dryer load weight variation with time. For these particular tests, environmental conditions of the air going to the dryer where set to emulate a production area of Santander in Colombia (T=28°C, RH=57%), and the results showed great agreement with other experimental studies [12,13].
4. Conclusions
The automatic humidification system integrated to the experimental facility allows to configure a high capacity air conditioning unit to support drying processes, especially for the construction of drying curves of agro-industrial products. The use of a robust system to control temperature and humidity of the air for drying applications is the most important outcome. In this experimental device it is possible to use different control strategies in order to obtain the particular air conditions required in the dryer under test; simple on/off control strategy combined with fuzzy control techniques showed good results and a low computational cost. Finally, the use of a DDE server to link the PLC to a computer has provided an easy and inexpensive way to process experimental data.

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