EDUCATION FOR CHEMICAL ENGINEERS XXX (2016) XXX–XXX

Contents lists available at ScienceDirect

Education for Chemical Engineers

journal homepage: www.elsevier.com/locate/ece

Design of a laboratory experiment for the performance analysis of a retrofitted tray dryer unit

S.M. Zakir Hossain[a,*], Noureddine Mansour[a], Nahid Sultana[b]

[a] Department of Chemical Engineering, University of Bahrain, P.O. Box 32038, Bahrain
[b] Department of Computer Science, University of Dammam, Building 600, Main Campus, Saudi Arabia

ARTICLE INFO

Article history:
Received 10 March 2016
Received in revised form 28 September 2016
Accepted 12 October 2016
Available online xxx

Keywords:
Tray dryer
Analog system
LabVIEW
Computerization
Design of experiment

ABSTRACT

Drying of products and raw materials is a widely used procedure in many manufacturing processes and chemical plants. The work described aims to improve the learning experience of students in a senior level undergraduate chemical engineering laboratory. The tray dryer unit used in the experiment was first retrofitted with a PC, a data acquisition card and LabVIEW software. Then a 2^k full factorial design and analysis of variance (ANOVA) were used to analyze the operation of the retrofitted dryer by the variation of two parameters: air temperature and velocity. The interactive effects of these parameters on the drying rate were also evaluated. Air temperature has the most significant effect on the drying rate, while the air velocity does not have a significant effect. Furthermore, interactive effects were not observed for both parameters. The results indicate that the performance of the retrofitted unit has improved by the incorporation of the intuitive and easy to use interface, which allows the students to monitor dynamic data and control the unit in real-time. Results of the student survey indicate that the level of understanding of process design and optimization has increased upon course completion. Most of the students believe that the lab is challenging and interesting, and would be worthwhile for lifelong learning. Overall, this approach not only exposes students to a hands-on industrially relevant unit operation, but it also complement classroom teaching on LabVIEW and statistical design of experimental concepts.

1. Introduction

Drying, which is the final removal of water or another volatile liquid from a wet solid, is performed before packaging some products to improve their storage life and reduce the transportation costs by lowering the weight of a product. Drying is a complex unit operation involving transient transfer of both heat and mass along with several processes, such as physical or chemical transformations that can change the product quality. Physical changes that may occur include: shrinkage, puffing, crystallization, glass transitions etc. In some cases, desirable or undesirable chemical or biochemical reactions that can cause changes in color, texture, odor, or other properties of the solid product may occur. Almost all manufacturing processes require the drying of a product or raw material and the equipment used in these industrial operations depend on the particular process and type of material being dried. For example, the equipment used for food processing must meet tougher requirements than those used for producing fertilizer. Thus, the drying process is governed by the relative importance of several factors including heat sensitivity, porosity, bulk density, particle size etc. (Margaris and Ghiaus, 2006; Kotwaliwale et al., 2007).

A number of chemical engineering laboratory drying experiments, including microwave drying of sand (Steidle and Myers, 1999), and convection drying of a towel, have been

* *Corresponding author*. Fax: +973 1768 0935.
E-mail address: zhossain@uob.edu.bh (S.M. Zakir Hossain).

http://dx.doi.org/10.1016/j.ece.2016.10.001
1749-7728/

reported in the literature (Nollert, 2002). A bench-scale experimental drying apparatus (Moor, 2001) and the statistical treatment of drying data (Prudich et al., 2003) have also been reported. However, to the best of our knowledge, studies on simple upgrading of the drying unit and the incorporation of a statistical experimental design element in laboratory drying experiments have not been reported. A tray dryer is considered in this study as it is one of the most common unit operations found in the process industry (Colak and Hepbasli, 2007; Corzo et al., 2008; Ghasemkhani et al., 2016; Aviara et al., 2014). Besides, students can study aspects of fluid mechanics, surface chemistry, solid structure, and mass and heat transfer associated with the general drying process using a tray dryer. Fine particles of the solid substance that needs drying is evenly distributed on the tray, which is heated through conduction or radiation using hot air swept across the tray. However, for many years, students have conducted experiments on the unit using instruments which are virtually obsolete in modern industry, making it very tedious and time consuming to perform any experiment. For example, wet and dry bulb temperatures of air are measured using an aspirated psychrometer and data are manually collected using a stop watch. An advanced laboratory setup using new equipment is a costly option for academic institutions. An alternative low-cost solution is to retrofit the existing laboratory containing proven systems with computer-controlled data acquisition systems and to develop custom-written software to suit the existing experimental modules.

Therefore, one of the objectives of this study was to overcome the constraints of the existing system and to make use of modern teaching and learning tools by incorporating computer-based educational tools for student use, either in the lectures or in the laboratory or both (Ertuggrul, 2000). Accordingly, the tray dryer unit was retrofitted locally with a PC, USB-120LS data acquisition card (Measurement Computing), and custom-written LabVIEW (Laboratory Virtual Instrument Engineering Workbench) software to suit the existing laboratory experiments. LabVIEW was used because it is easy to learn, adapt, and apply. Some of its features include a graphical user interface (GUI), built-in engineering-specific libraries of software functions, hardware interfaces, data analysis, and visualization. Software allows the users to select their own input values and manipulate them in a manner that resembles a real laboratory (Essik, 2009; Xu, 2015; Agarwal et al., 2013; Popović et al., 2011; Wang et al., 2007).

Another objective of this study was to develop a laboratory where students are exposed to statistical experimental design (DOE) concept in a quasi-industrial setting. The DOE concept is an important statistical technique for developing a black box model correlating various process variables or factors. The technique also uses statistics to obtain meaningful relationships through a minimum number of experiments (Montgomery, 2001; Montgomery and Runger, 2006; Aftanasar et al., 2015; Box et al., 1978). Students can easily evaluate which subset of the process variables has the most significant effect on process performance or response variable by performing controlled tests and analyzing the results. They can also investigate the interactive effects among the process variables. Accordingly, a retrofitted tray dryer unit was used to perform a real drying process and analyze the results. A 2^k full factorial design and analysis of variance (ANOVA) were used to evaluate the operation of the dryer unit by manipulating two main variables: i.e., air temperature and air velocity

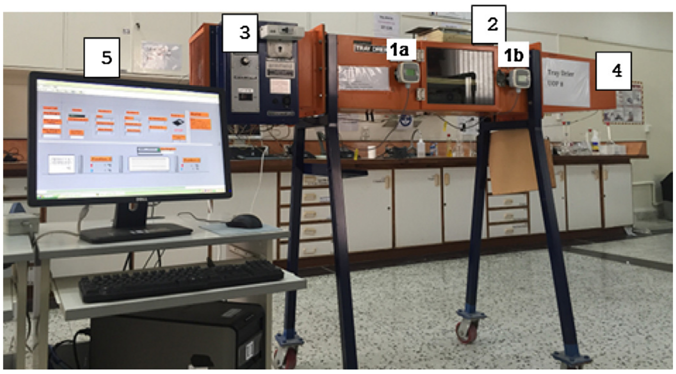

Fig. 1 – Armfield UOP 8 tray dryer unit where, temperature and relative humidity sensors: before (1a) and after (1b) the trays, electronic balance (2), air-fan with speed controller (3), air outlet duct section (4), PC running the LabVIEW software (5).

on a response variable (drying rate). The most significant parameter and the interactive effects of the drying process are also reported. Overall, hands-on experimental learning through the application of LabVIEW and statistical experimental design can enhance the understanding of the course subject by the students. The retrofitted unit can be a potential industrially relevant pivotal tool for a wide range of experiments, including the performance analysis of drying of food and biological materials in real-time.

2. Experimental setup and procedure

2.1. *Description of the apparatus*

An Armfield UOP 8 type tray dryer unit was used in this study and the retrofitted version of the unit is shown in Fig. 1. The tray dryer consists of an air duct mounted on a frame standing on the floor to provide a comfortable working height for the operator. Air is drawn into the duct through a mesh guard by a motor-driven axial-flow fan impeller with a controllable speed (3) to produce a range of air velocities. The air passes over a computer-controlled electrically heated element to provide a variation in air temperature up to a maximum of 80 °C at low air velocities. The air passes into the central section of the duct where four trays containing the material to be dried (e.g., wet sand) are suspended in the air stream. The trays are mounted on a support frame, which is attached to an electronic balance placed above the duct on which the total weight is continuously indicated (2). The trays are inserted or removed from the duct through a latched side door with a glass panel for viewing purposes. After passing over the drying trays, the air is discharged to the atmosphere through an outlet duct section where a digital anemometer is used to measure the air velocity (4). Temperature and relative humidity of the heated air before and after the trays are monitored continuously using appropriate sensors (1a and 1b). All dynamic data are collected through a PC running the LabVIEW software (5), which is programmed specifically for this experiment.

2.2. *Instrumentation and data acquisition*

The air temperature and the relative humidity upstream and downstream of the trays are measured (Fig. 1a and b) using duct type temperature and humidity sensors (SE-MFD3110) with a range of 0–100% for relative humidity (±2% RH) and