Work in Progress – Troubleshooting of an Electrohydrodynamic (EHD) Drying System

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Abstract –Dehydration is very important for food preservation during storage and transportation. Today, food dehydration is done mostly by forced air convection. Forced air convection uses a psychrometrically controlled air flowing over food products to remove water content. This process consumes a lot of energy due to high airflow rates. A method to reduce energy consumption, called Electrohydrodynamic drying (EHD), uses high voltage electrodes at low current suspended over the food product to create a secondary airflow. The high voltage electrode creates an electric field where current is passed through the air to a grounded plate that a food sample sits on. This passing of current through the air creates a secondary airflow due to interaction between the flowing electrons and air molecules. This secondary airflow allows a significant decrease in the primary airflow due to forced convection, therefore decreasing the total power consumption.

Some research in EHD drying has been conducted in partnership between ONIRIS (a food science engineering higher education institution in Nantes France) and Grove City College since 2013. The research has involved the Grove City College study-center study-abroad program based in Nantes France. The program allows for Mechanical and Electrical engineering students to study abroad for a full semester. In the 2015-2016 academic year, a team of senior electrical engineering students participated in the study abroad program. The students were required to complete a senior design project. The goal of this project was to replicate the EHD drying experimental apparatus used at ONIRIS, but at a significantly reduced cost. The purpose of this study is to present the work done on improving the design of the EHD drying system developed by the electrical engineering team during a three-semester independent study

I. Introduction

Drying food is a high energy process that is used to reduce the amount of water mass in food for: extending self-life, reducing packaging, storage, handling and transportation costs, and out-of-season availability[1]. Drying is primarily done today by forced convection. This process requires a significant amount of power due to conditioning air. One alternative to forced convection alone is the use of Electrohydrodynamic (EHD) drying. EHD is a solution to be used in conjunction with forced convection to limit the total power consumption of the food drying process. Electrohydrodynamic drying is a process where a current passed through the air from a high voltage electrode to a grounded plate where the food sample is placed. This passage of current through the air creates a secondary airflow due to the interaction between flowing electrons and air molecules. This increases the convective heat transfer coefficient which increases the drying rate of a sample. This secondary air current acts as the primary driving factor for dehydration. This results in the ability to decrease the primary airflow which in turn reduces energy consumption. The main role of the primary airflow is to evacuate the accumulated moisture in a drying chamber due to the food dehydration.

Research in this field has been conducted in relationship between Grove City College (GCC) and Oniris in Nantes, France. Oniris is an establishment under the jurisdiction of the French Ministry of Food, Agriculture and Fisheries that offers studies in Veterinary Medicine, Food Sciences and Engineering. Oniris is an activity partner school to Grove City College's Study Center program which offers full semester study abroad for mechanical and electrical engineering students at GCC. Since 2013, all research in EHD drying has been conducted at the Oniris campus in partnership with a visiting faculty member from GCC. Figure 1 shows a diagram of the experimental set-up used at Oniris. The set-up consists of a rectangular airflow channel (6 x 7.5 x 80 inches) used to dry humid test specimens (representing food products) by means of forced convection with and without an electrostatic field (i.e. EHD and FC drying). The channel connects to an air handling unit used to control the psychrometric conditions, and the flow rate of the air entering the channel. A wire-electrode(s) suspended above the test specimen connect to a high voltage generator to produce an electrostatic field. The airflow channel is placed on a table top which has a square hole cut to fit a tray that holds the test specimen. The tray is constructed with a copper bottom and polystyrene borders and holds in place a 6 x 6 x 0.4 inch test specimen exposing the upper surface. The copper bottom of the tray is grounded to allow current to flow from the wire-electrode through the test sample. The tray is placed on a weight scale to measure the change in mass of the test specimen due to moisture loss during the drying process. The weight scale is covered with aluminum foil to create a Faraday cage. The surface of the test specimen is aligned to be flush with the bottom surface of the airflow channel. The system also can measure changes in the heat transfer coefficient by replacing the test specimen tray with a heat plate. The heat plate temperature is controlled by applying a low voltage (< 10 V) to the plate for it to reach a specified temperature above ambient (typically 50 °C). The temperature of the hot plate is measured via an infrared sensor that is positioned on the top of the drying channel through a penetration. Changes in the heat transfer coefficient are measured as a function of the decreasing hot plate temperature when a voltage is applied to the wire-electrode.

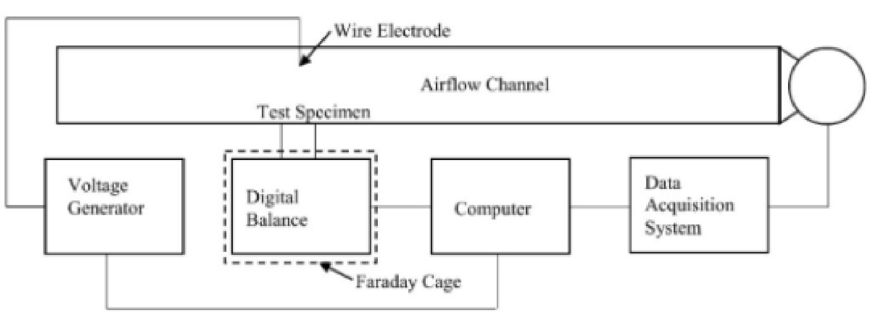


Figure 1: Experimental set-up used at Oniris.

The goal of this project was to duplicate, as much as possible within a limited budget, the experimental set-up used at Oniris shown in Figure 1. The new set-up would then be used to continue research on the GCC campus in the US, in tandem with Oniris in France.

The reconstruction of the experimental setup consisted of two phases. The first phase was conducted by a 2015 – 2016 electrical engineering senior design project. They were tasked with replicating the EHD portion of the experimental set-up in figure 1. The students who were part of the design team also participated in the full-semester study abroad program. Phase two of this projected is currently underway with a 2017 – 2018 mechanical engineering senior design team. Their goal is to construct the drying channel paired with an air handler to control the psychrometric conditions of the primary airflow through the channel funded by a grant awarded by ASHRAE (The American Society of Heating, Refrigerating and Air-Conditioning Engineers). The purpose of this paper is to present some of the work done troubleshooting part 1 of the system through an independent study.

II. System Overview

There are two different experiments that can be run on the current EHD system at GCC. The first experiment measures the increase in the heat transfer coefficient of a hot plate set to a constant temperature. A diagram of this experimental set-up can be seen on the right with figure 2a. A wire-electrode supplied with a high voltage (>10 kV) is suspended above the hot plate. The voltage applied to the suspended electrode causes current to travel through the air to the hot plate causing a corona wind. The heat transfer coefficient is then calculated based on the decrease in the hot plate temperature.

The second experiment measures the moisture loss of a food sample. In this set-up, which can be seen in Figure 2b, the hot plate is replaced with a conductive plate placed on a mass balance protected by a Faradays cage. The food sample is placed on the plate and the mass loss due to electrohydrodynamic drying is measured over a time interval predetermined by the user.

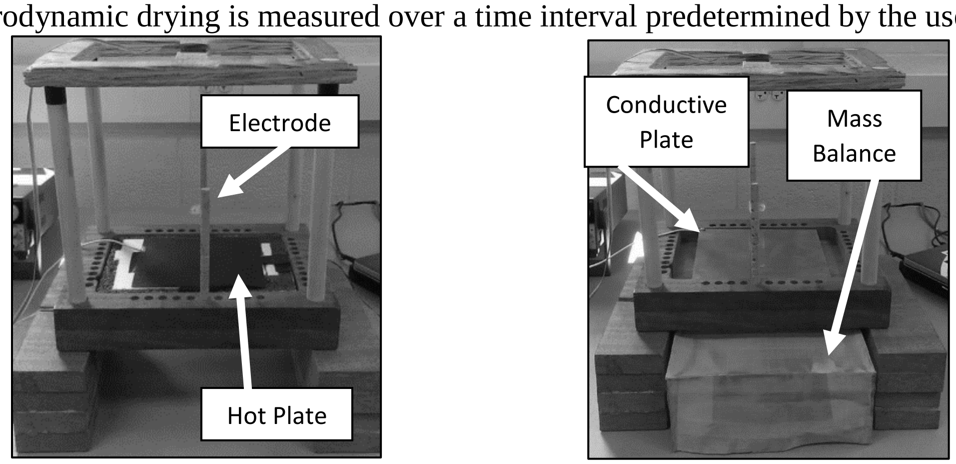


Figure 2 (a) Left – old heat transfer experimental set-up (b) Right – Old moisture loss experimental set-up

III. Timeline for the Independent Study

This project took place over the course of three semesters and was carried out by both an electrical and mechanical engineering student. This paper concentrates on the work from the mechanical engineering side. First, a new solid steel Faraday's cage was manufactured to replace the existing soldered coper mesh cage. The old and new cages can be seen in Figure 3. The steel faraday's cage has a viewing area to read the scale readings and a ground connection on the back.

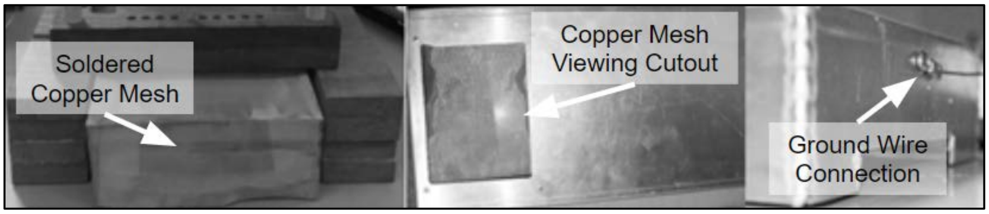
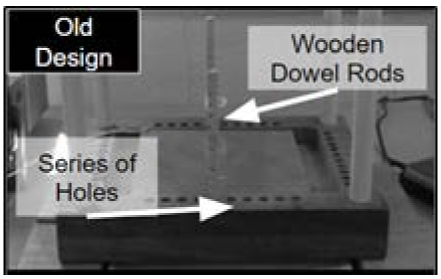


Figure 3: Old copper mesh Faraday's cage (1 photo to the left). The new steel Faraday's cage (2 photos to the right)



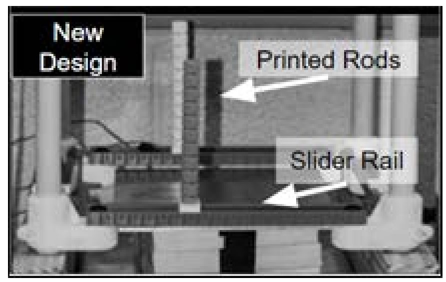


Figure 2 Close view of redesign

Second, the testing area needed to be designed in such a way as to allow different wire-electrode(s) configurations. In a typical EHD drying experiment, a wire-electrode(s) is suspended above a food product, or heating plate, supplied with a high voltage (10 – 25 kV). The experiments investigate the effects of different wire-electrode(s) configurations on drying efficiency. Wire-electrode(s) can be arranged perpendicular or parallel to the main airflow. Therefore, to allow for multiple wire-electrode configurations over the testing area, a slider rail system was designed (see Figure 3b). Figure 4 shows a closer view of the design details. This concept resulted in numerous iterations before arriving at the final design. The design consists of a vertical rode with notches used to fasten the wire-electrode. Each notch is located at 1 cm increments above the testing area. The rods are attached to a slider which allows the rod to be moved along the edge of the testing area. There is a slider positioned along each of the four edges of the testing area. This system was designed to replace the existing wooden dowel rods which were placed in one of a series of holes surrounding the perimeter of the testing area. This design was recently manufactured and implemented. A few tests were conducted using the slider rail design to prove consistent results. Two 1.5-hour heat transfer tests were completed along with two 1.5-hour water loss experiments. In addition, an eight-hour food moisture loss experiment was run to validate the systems ability to run for longer periods of time. The results of these experiments showed that the slider rail design was able to position the wire electrode(s) without causing issues with data collection (data to shown in presentation due to paper length limit).

IV. Conclusion

The purpose of this three-semester study was to troubleshoot and improve upon an EHD food drying system built by a 2015 – 2016 electrical engineering senior design project at GCC. This study analyzed the setup and improved the design for test reliability for future research at Grove City College. Currently, the final phase of the project is underway by a 2017 – 2018 mechanical engineering senior design team. The goal is to integrate the EHD drying system into an airflow channel paired with an air handler to control the psychrometric conditions of the primary airflow through the channel.

V. References

1. Moses, J, T Norton, K Alagusundaram, and B Tiwari, “Novel Drying Techniques for the Food Industry,” Food Engineering Reviews 2014; 6:43-55