JoVE: Science Education

Using a Tray Dryer to Investigate Convective and Conductive Heat Transfer

--Manuscript Draft--

Manuscript Number:	10438
Full Title:	Using a Tray Dryer to Investigate Convective and Conductive Heat Transfer
Article Type:	Manuscript
Section/Category:	Manuscript Submission
Corresponding Author:	Kerry Dooley UNITED STATES
Corresponding Author Secondary Information:	
Corresponding Author's Institution:	
Corresponding Author's Secondary Institution:	
First Author:	Kerry Dooley
First Author Secondary Information:	
Order of Authors:	Kerry Dooley
Order of Authors Secondary Information:	

PI Name: Michael Benton

Science Education Title

Using a Tray Dryer to Investigate Convective and Conductive Heat Transfer

Overview

Commented [HK1]: • The overview lists the goal, procedure and comparable technologies, however, it should also provide a short statement about significance of this experiment. Why are we interested in determining the drying rate and what is the importance about the convective and conductive heat transfer?

Goal: We will use the process of sand drying in a ~~G.U.N.T Hamburg~~ tray dryer in order to relate convective and conductive heat transfer to drying rate.

Comparable Technology: A variety of dryer types exist. Adiabatic dryers use direct contact with gases to dry solids, while non-adiabatic use methods other than heated gas contact to dry[1]. Adiabatic dryers use convection, while non-adiabatic dryers use a variety of methods, including conduction, radiation, and radio frequency drying[1]. Dryers can be for batches or continuous use[1]. Tray dryers are one type of batch dryer, which also includes fluidized-bed dryers, freeze dryers and vacuum dryers, and are used by a variety of industries including pharmaceuticals and chemicals[1]. Continuous dryers on the other hand are common to large volume product industries, such as the food industry[1].

Procedure: Sand was measured and spread evenly over a tray along with DI water. The temperature of the sand, air in the tray dryer, humidity of the outlet stream and weight of the tray were measured before starting the equipment and at 5 minute intervals after startup for a total of 45 minutes. Three different power settings (1000 W, 1500 W and 2500 W) for two different air flow rates; each were used to record a total of six data sets. Drying rate was measured for each set. The rate was measured by weighing the sand/water mixture and subtracting the weight of the dry sand every 5 minutes. A slope of the curve was taken to estimate the drying rate for each set of conditions.

The equipment used to perform the experiment is a tray dryer. It dries solids by flowing heated air over the solid, a convective process. A tray is filled with wet sand and into the dryer to begin the process. The dryer's adjustable fan and heater allow for continuous variations in flow rate from the fan through the drying channel, and heat duty variations in 500 watt increments. As the dryer operates, water evaporates from the sand into the air, and measurements are taken.

Principles

Heat transfer is driven by the temperature difference between the sand and the surrounding air. Newton's Law of Heating (Equation 1) can be used to model the heat transfer between the heated air and sand-air interface to obtain an experimental heat transfer coefficient.

$$q = \dot{m}\Delta H_{vap} = h\,(T_a - T_s) \qquad \text{Equation 1}$$

Where q is the heat, $\dot{m}$ is the mass flow, ΔH_{vap} is the delta enthalpy of vaporization, h is the entropy, T_a is the air temperature, and T_s is the sand temperature.

In order to obtain an experimental mass transfer coefficient, the transfer of water from sand to air will be modeled as mass transfer flowing across a true phase boundary. The drying rate equation (Equation 2) is this model.

$$N_{Ao} = k_y\,(C_s - C_\infty) = \dot{m}/A \qquad \text{Equation 2}$$

Where N_{Ao} is the drying rate, k_y is the mass transfer coefficient, C is the concentration, and A is the area of the boundary. Concentrations of water in the sand (C_s) and air (C_∞) will be obtained by used of mass balance and psychrometric charts, respectively. These will be used to solve for the drying rate.

Theoretical values can be compared to the experimental data by calculating heat and mass transfer coefficients. The theoretical heat (Equation 3) and mass (Equation 4) transfer coefficients can be obtained from the properties of the substances involved from correlations.

Commented [HK2]: What exactly is meant by the properties of the substances? Would it be worthwhile for the students to write out Re, Pr, and Sc? Or would you suggest that they are familiar enough with this topic, that no further clarification is needed?

Commented [MC3R2]: These are terms that students should know how to use. Defining them would also significantly increase the length of this section.

$$h = 0.664\,(Re^{0.5}Pr^{0.33}k)/L \qquad \text{Equation 3}$$

$$k_y = 0.664\,(Re^{0.5}Sc^{0.33}k)/L \qquad \text{Equation 4}$$

Where Re is the Reynolds number, Pr is the Prandtl number, Sc is the Schmidt number, and L is the length.

Procedure

1. 500 grams of sand and 150 milliliters of water are to be mixed together for each run in the unit experimental tray, with the unit off.
2. The sand and water mixture should be placed in a tray and spread evenly. The tray should then be placed in the drying chamber.
3. Turn on the main unit, then turn on the blower and heater.
4. The experiment will consist of four runs, each testing a different combination of one of two fan and heat settings. The three air velocities should range from 0.8 ft/s to 2.0 ft/s (one high, medium, and low) with a constant temperature around 195^{0}F. The three temperature should range from 130 to 200^{0}F with a constant air velocity of 1.8 ft/s.
5. Each trial should be run for 45 minutes, with measurements taken every 5 minutes. The data collected should include inlet air temperature, sand temperature, sand weight, outlet air temperature, outlet air flow, dry bulb temperature, and wet bulb temperature. Use the digital thermometers for temperature readings, air flow settings for air flow, and digital scale for sand weight.

Commented [HK4]: What is meant by the dry and wet bulb temperature?

Commented [MC5R4]: These are different temperature measurements, normally used together for psychrometric chart readings. These concepts are all taught in intro level courses.

6. Repeat the process for each set of settings, totaling four unique runs.
7. The wet and dry bulb temperatures should be used to find the relative humidity with the sling psychrometer, then comparing to psychrometric charts.

Commented [HK6]: How is a sling psychrometer used? Will charts be provided?

Commented [MC7R6]: The charts are a common tool in many chemical engineering textbooks or online. They are all the same, so students should not have any issues finding them.

8. Use the relative humidity to find the absolute humidity by use of psychrometric charts or similar tools, which gives the concentration of water present in the air.
9. The change in mass of the wet sand will be used to calculate the concentration of water in the sand. Use the digital thermometers and digital scale measurements. This can be obtained by totaling the mass of the wet sand at any time interval being studied, then subtracting the initial mass of the sand to obtain the current mass of water. Divide by the current total mass to obtain the current concentration of water in the sand.
10. The measured temperatures will be used to calculate the heat transfer coefficients (Equation 1).

Commented [HK8]: Is absolute humidity determined just by chart comparison? Once this is known, how do you determined the water concentrations in the air? Is there an equation? Could you please elaborate on this.

Commented [MC9R8]: This is all directly from the chart reading. The absolute humidity is the concentration of water in the air

Commented [HK10]: Could you provide/demonstrate the calculation for the concentration of water in the sand.

Commented [HK11]: This will be done using equation 1, correct?

Commented [MC12R11]: Yes.

Representative Results

The moisture content of sand decreased linearly over time. As expected, evaporation rate was found to increase with larger flow rate and heat duty. According to their equations, both heat and mass transfer coefficients are directly proportional to the evaporation rate at the sand-air interface. Theoretical values of heat and mass transfer coefficients were found to have a strong positive correlation with a R^2 of 99%. The experimental values only showed a weak correlation after testing.

The relationships between air flow and evaporation rate and between temperature and evaporation rate both increased linearly (Figure 1, Figure 2). Increased air flow (Figure 1)and increased temperature (Figure 2) both increased the evaporation rate. These graphs show that when air flow or temperature increase and the other variable is held constant, evaporation rate will increase at an equivalent rate, following a positive linear trend. The air flow variation test was a measure of convective heat transfer, while the temperature variation test was a measure of conductive heat transfer. The sum of the two tests shows that both convective and conductive heat transfer follow a linear relationship with evaporation rate.

There are many sources of error in the measurements with the greatest sources for error being the relative humidity and temperature of the air-sand interface. Also, air flow rate effect on the weight of the tray was deemed unimportant but it is a source of error. Some of this error may have also reduced the correlation of the heat and mass transfer coefficients. These coefficients were calculated theoretically and proven to be correlated. However the experimental data did not show a significant trend, despite being theoretically similar.

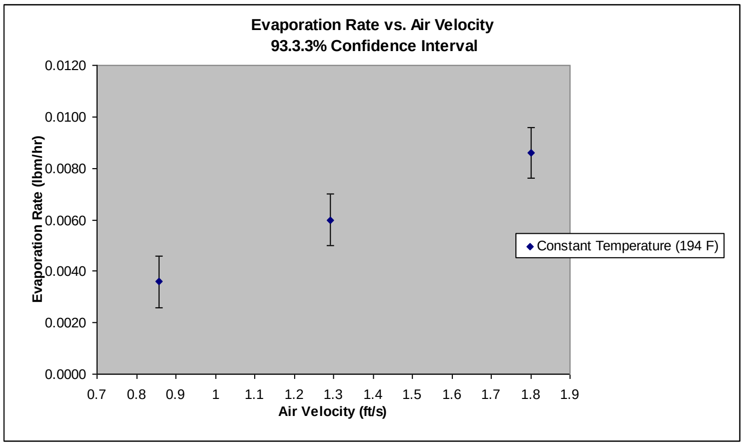

Figure 1: Depiction of the relationship between air velocity and evaporation rate, which increased linearly.

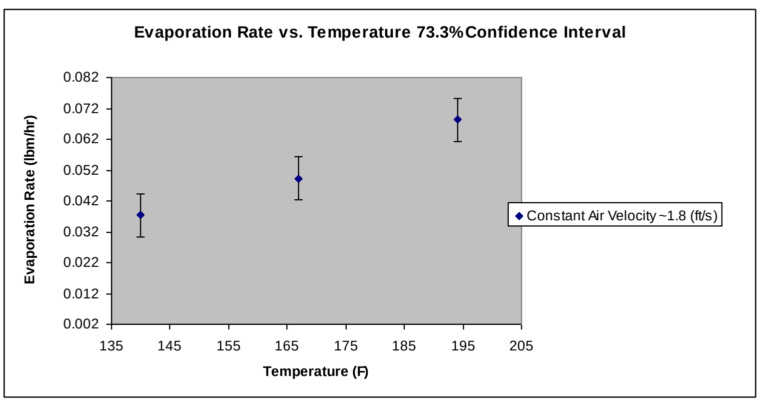

Figure 2: Depiction of the relationship between temperature and evaporation rate, which increased linearly.

Summary

A G.U.N.T Hamburg Tray Dryer was used to measure drying rate in respect to convective and conductive heat transfer. Sand was weighed and water added. Using the dryer at three different power levels and two different flow rates, six experimental data sets were found. Measurements were taken by weighing the sand/water mixture at five minute intervals.

This experiment made use of Newton's Law of Heating, drying rate modeling, and heat and mass transfer modeling. Heat and mass transfer coefficients were determined with the use of a boundary layer model. Theoretically, the heat and mass transfer coefficients show a very strong positive linear correlation. Even though the experimental results showed a positive trend as well, the data was too inaccurate to display any significant correlation between the two.

Applications

Tray-drying can be used in a variety of fields. One such field is pharmaceuticals. In pharmaceuticals, tray dryers are used to dry many different base materials, including sticky, granular, and crystalline materials[2]. Many plastics used in pharmaceuticals can be dried in tray dryers[2]. Additionally, precipitates, pastes, and other wet masses can be dried with a tray dryer, along with crude drugs, chemicals, powders, and tablet granules. Even some equipment is dried in the dryers[2]. Tray dryers offer many advantages to this industry, since they are used for batches, which can vary in size and be handled without losses[2]. The dryers are also readily adjusted to accompany other materials in an efficient manner[2]. In some cases, tray dryers in a vacuum are used to dry heat sensitive products like vitamins[2].

Tray dryers are also used in food processing[3]. Food can be spread out thinly and evenly onto the trays for drying[3]. Depending on the type of food, drying can be performed by heating with air moving across the trays, conduction from heated trays or shelves, or radiation form other heated surfaces[3]. Air can be used with the additional benefit of removing moist vapors, though this can be a problem for some foods[3].

Sources

1. "Solids Drying: Basics and Applications - Chemical Engineering." *Chemical Engineering Solids Drying Basics and Applications Comments*. N.p., n.d. Web. 12 Jan. 2017.

2. "Pharmainfo.net." *Tray dryer by Saraswathi.B*. N.p., n.d. Web. 12 Jan. 2017.

3. "Unit Operations in Food Processing - R. L. Earle." *Unit Operations in Food Processing - R. L. Earle*. N.p., n.d. Web. 12 Jan. 2017.