**PI Name: Michael Benton**

**Science Education Title**

Using a Tray Dryer to Investigate Convective and Conductive Heat Transfer

**Overview**

Goal: We will use the process of sand drying in a ~~G.U.N.T Hambur~~g 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 dry1. Adiabatic dryers use convection, while non-adiabatic dryers use a variety of methods, including conduction, radiation, and radio frequency drying1. Dryers can be for batches or continuous use1. 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 chemicals1. Continuous dryers on the other hand are common to large volume product industries, such as the food industry1.

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 = 𝑚̇∆𝐻𝑣𝑎𝑝 = ℎ(𝑇𝑎 − 𝑇𝑠 ) Equation 1

Where q is the heat, 𝑚̇ is the mass flow, ∆𝐻𝑣𝑎𝑝 is the delta enthalpy of vaporization, h is the entropy, Ta is the air temperature, and Ts 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.

𝑁𝐴𝑜 = 𝑘𝑦 (𝐶𝑠 − 𝐶∞) = 𝑚̇/𝐴 Equation 2

Where NAo is the drying rate, ky is the mass transfer coefficient, C is the concentration, and A is the area of the boundary. Concentrations of water in the sand (Cs) 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.

ℎ = 0.664 (𝑅𝑒0.5𝑃𝑟0.33𝑘)/𝐿 Equation 3

𝑘y = 0.664 (𝑅𝑒0.5𝑆𝑐0.33𝑘)/𝐿 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 195⁰F. The three temperature should range from 130 to 200⁰F 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.
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.
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).

**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 𝑅2 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 materials2. Many plastics used in pharmaceuticals can be dried in tray dryers2. 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 dryers2. Tray dryers offer many advantages to this industry, since they are used for batches, which can vary in size and be handled without losses2. The dryers are also readily adjusted to accompany other materials in an efficient manner2. In some cases, tray dryers in a vacuum are used to dry heat sensitive products like vitamins2.

Tray dryers are also used in food processing3. Food can be spread out thinly and evenly onto the trays for drying3. 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 surfaces3. Air can be used with the additional benefit of removing moist vapors, though this can be a problem for some foods3.

**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.