



Design of an Efficient Drying System

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Problem Introduction

Dean Smith, of S & S Farms in western Oklahoma, is a producer of super-hot chili peppers for use in the pharmaceutical industry. His peppers are used for a variety of different products, including Icy Hot and pepper spray. Before processing and shipping his peppers he must reduce the moisture content to 5 %. The goal of *Spicy Solutions* is to develop a time and cost effective drying method to reduce the expense associated with the increasing price of natural gas, by developing a continuous flow drying process.

The current drying process consists of peanut wagons to hold the peppers, fifteen Peerless 103 dual 3-phase dryers that have natural gas burners to heat the air, and a blower that forces the air into the false bottom of the peanut wagon. The peanut wagons are placed under open-sided barns that are exposed to the environment. Currently the dryers raise the ambient air temperature 20°F (-6.7°C) to 30°F (-1.1°C). The current drying time for the peppers ranges from 48 hours at the beginning of the drying season to about 18 hours at the end of the season. The peppers remain in the field on the plant for as long as possible which allows them to dry naturally, thereby reducing the additional energy required to dry them. After they are harvested, they are stored in a barn until they are placed in the peanut wagons for drying. After the peppers have been dried to the desired moisture, they are milled into a powder before being shipped off to the extraction company.

For our project, the process must accommodate a total of 1,700,000 pounds (773,000 kg) of peppers per year, and approximately 60,000 pounds per day (27,300 kg/day). A main limitation of our project presented by the client is reducing the amount of natural gas used, which will lower the cost of the process. The peppers also need to be processed in a timely manner to maintain the speed of the milling process and reduce the chance of spoilage.



Spicy Solutions spent the spring semester performing calculations and running tests with different conditions to determine the best design. At the conclusion of the year *Spicy Solutions* would like to have a final design that is easy to implement and maintain. We would like to develop a solution that would be easy to implement to reduce problems associated with the incorporation of our solution. Reducing the maintenance will reduce the labor cost and the possibility of slowing the process.

Previous Work

Patents

Spicy Solutions started researching patents to determine what was in use and if our design ideas would infringe on existing patents. We found several patents on the topic, but none presented much concern. Below is the team's understanding of the patents that were found.

US Patent Application No. 20,070,160,729 Capsinoid-Containing Dried Chili Pepper Product and Method of Drying the Same Date of Issue: July 12, 2007

The purpose of this patent is to discover suitable drying conditions that prevent the decomposition of capsinoid compounds and increase the yield when drying capsinoid-containing chili peppers. Another purpose is to maintain the stability of capsinoids during drying of chili peppers. Chili peppers cut either before or during drying have increased surface area and ruptured outer skin. These conditions accelerate the evaporation of internal moisture, enhance drying efficiency and permit rapid drying. Frequent and uniform mixing and stirring causes moisture to evaporate evenly from the peppers, thus preventing uneven heating. The patent covers stirring at least once per hour. An air speed of 0.98 ft/s (0.3 m/s) or greater works well for batch drying. An air speed of 0.66 ft/s (0.2 m/s) or greater works well for continuous drying. An air temperature of 149°F (65°C) to 176°F (80°C) is used. The hot air is directed through the



bulk chili pepper material. These conditions prevent excessive heating of capsinoid and thus suitably prevented it from decomposing.

The patent covers drying Manganji peppers, Shishito peppers, Fushimi Amanaga peppers, and CH-19 Sweet peppers. It specifies that weight of peppers is reduced to less than 20% and the moisture content is reduced to less than 10% of the raw fruit. It covers the following driers: band-type, fluidized bed-type, draft-type, rotating-type, spraying-type, stirring-type, box-type, moving bed-type or drum-type. It further covers drying with a convective heat-transfer dryer, using either continuous stirring or stirring at least once an hour.

U.S. Patent No. 7,137,580 System and method for pulverizing and extracting moisture

The patent covers an apparatus for pulverizing material and extracting moisture from material. It is composed of an inlet tube, a venturi coupled to the inlet tube, an airflow generator to generate airflow with an inlet aperture, an axel coupled to the airflow generator, a balancer coupled to the axel to compensate for imbalance in the axel during rotation, and a housing at least partially encompassing the airflow generator. An outlet communicates with the input aperture, the airflow generator communicates with the venturi to direct the airflow through the venturi, and toward the input aperture.

The material introduced into the airflow passes through the venturi and is subject to pulverization and moisture extraction. A material flow rate is measured by an acoustic emission sensor, which receives the resonant frequencies generated by the material passing through the airflow generator. The material flow rate is measured to avoid overloading the system. This patent is specific to the balancing apparatuses and methods for the rotating axel.

U.S. Patent No. 7,059,550 System and method for pulverizing and extracting moisture



This patent is relevant to the same system as the previous patent, U.S. Patent 7,137,580. This patent is specific to the apparatuses that create, direct, and handle the air flow. It also covers the heat generation, pulverizing system, and material feed equipment. It contains the elaborate process of material flowing through the system. It also contains the communication between components.

U.S. Patent No. 7,040,557 System and method for pulverizing and extracting moisture

This patent is relevant to the same system as the previous patent, U.S. Patent 7,137,580. This patent is specific to the methods and apparatuses for the sensors, controllers, acoustic emission sensor, and the communication between apparatuses.

Sales Literature

Market research was an important part of the team's research. We were interesting in determining what is available and if the client is using the best product. Listed below are the results of our market research.

Peerless Dryers

Spicy Solutions looked at this information because the client is currently using the Peerless regular dryers. Other dryers that Peerless makes are whisper dryers, quiet dryers, which are a lot like the regular dryers but they produce less noise, and semi dryers, which have been tested to dry open-top semi containers in the same way as the wagon dryers.



Figure 1. Peerless 103 Dual 3-Phase Dryer

GT Mfg. Inc Grain Dryer Specs.

These dryers are recirculating batch grain dryers that would not be feasible for our project because of the set up of the dryers. They are geared more towards small grains and would not be able to accommodate the size of the chili peppers and the rate that they need to be dried. They would not be easily incorporated into the current process based on the way they hold the grain.

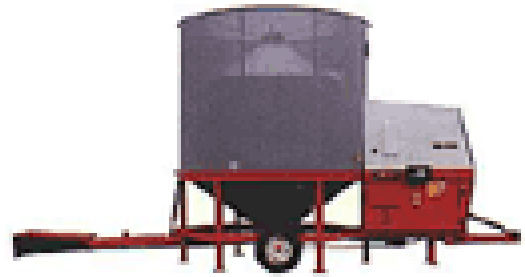


Figure 2. GT Mfg. Inc. Grain Dryer

Peanut Dryers-Diaka Model DDG 8000

This dryer is typically used for drying peanuts and seeds. The dryer removes the humidity out of the air and uses a heat pump cycle to generate drying heat. It is most efficient on summer days, making it less feasible for our project since most drying occurs in the middle of the winter. To supplement the heat pump and increasing the temperature, it has a LPG back-up burner attached that can be used during the winter months. These dryers are not a feasible for this project because they produce half of the volumetric flow rate and horsepower.



DAIKA Model DDG 8000

Figure 3. DAIKA Model DDG 8000

Blueline Crop Dryers

These dryers are most often used to dry peanuts and they are built to fit most standard peanut wagons. All Blueline Dryers can be used with LP vapor or natural gas. They offer several different models of dryers, much like the dryers offered by



Figure 4. Blueline Peanut Dryer Model 2712

Peerless. The specifications on these dryers seem to be a lot like those of the Peerless dryers so it may not be feasible for the client to replace all of the current dryers with ones that will not provide much benefit.

Research Articles

Spicy Solutions was interested in determining other methods of drying agricultural products that might be able to be applied to our problem. Below is a summary of several articles that were found, and if they are applicable to our project or not.

The dissertation, *Modeling of Deep Bed Hop Drying by Dr. Marvin Stone*, presented the team with the idea of modifying the bed depth and also modifying the air temperature and flow. This dissertation concluded that:

1. “High inlet air temperatures promote high fuel efficiency
2. Deep drying beds promote high fuel efficiency
3. Layer drying promotes fuel efficiency through deeper beds
4. Recirculation of dryer exhaust can result in fuel savings with little increase in drying time
5. Modulation of airflow and inlet air temperature can decrease drying time and fuel consumption. If temperatures and airflow are not properly managed, loss in quality may result.” (Stone, 1982)

The article *Medium Scale Solar Crop Dryers for Agricultural Products* discussed two different drying systems that were used to dry onions and bales of hay using solar air heaters. The first dryer discussed uses a corrugated galvanized steel roof and a fan that can supply 11,900 ft³/min (5.6 m³/s) and a pressure drop of 747 Pa (Headly). For this dryer, the air is sucked into the ceiling space and ducted to a fan that blows into the plenum chamber with a perforated roof

at floor level. The bags of onions are placed on top of the plenum so the heated air does not bypass the product. This dryer doesn't have an auxiliary heating system since the farmer didn't think it was necessary (Headly). The second dryer uses a glazed 431 ft² (40 m²) solar collector

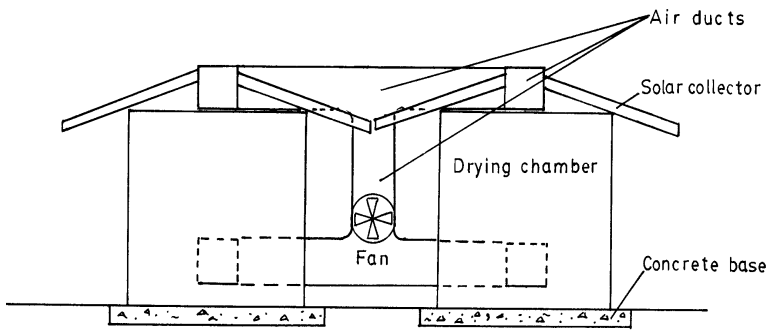


Figure 5. Dryer Set Up

connected to a fan. The drying chamber consists of two shipping containers that have been modified to improve the heat retention capabilities. The fan sucks air through the solar collector and then into the containers with the onions or hay bales. These

drying options will not work for this project most likely because the air used will not be warm enough to dry the peppers to the desired moisture content without a heater attached to the process.

The article *Dehydration of Food Crops Using a Solar Dryer with Convective Heat Flow* discussed the possible design based on the principles of convective heat flow and using it to dry food crops. By using a solar collector an ambient air of 90°F (32°C) and relative humidity of 80% could be heated to 113°F (45°C) at 40% relative humidity (Ayensu 1997). The crops were able to reach moisture content of <14%. The article also discusses the factor of free water in the product compared to the bound water. The use of solar energy is not applicable to this project given the season when the drying takes place.

The article *Design and Performance of an Air Collector for Industrial Crop Dehydration* reviews a test of the operation of unglazed and single-glazed solar collectors used to heat air. The collectors were tested in a range of sizes and lengths so that the pressure drops and heat transfer

rates would vary (Niles 1978). Although this article is geared to industrial size crop drying operations, it introduced the possibility of solar panels to reduce some of the cost of natural gas that the client is currently facing. Once again, the use of solar energy would not be cost effective for this project.

The paper *Curing Peanuts Using Continuous Flow Dryers* explained the results from a comparison of a single-pass continuous flow dryer, a recalculating batch dryer and a wagon drying process (Butts 2001). The study monitored drying time and quality of the peanuts after being dried. The results can be applied to the drying of peppers. The paper concluded that “using the continuous flow dryers were dried at a much faster rate than conventionally-cured peanuts” (Butts 2001). This information is applicable to this project since peppers are dried in a similar way to peanuts.

The presentation titled *Effects of Drying Procedure, Cultivar, and Harvest Number on Capsaicin Levels in Dried Jalapeno Peppers* discusses a study on how to harvest and process pepper to maintain the maximum amount of capsaicin (Pordesimo 2001). The study focused on the effects of cultivation, harvesting time and drying. The study concluded that a change in drying temperature “did not affect the concentration of total capsinoids in dried jalapeno peppers” (Pordesimo 2001). The information from this study can be easily applied to our study because it focused on non-food use peppers.

The article *Modelling of Thin-Layer Drying Kinetics of Red Chillies* investigates which temperature works best for drying peppers in a thin-layer dryer. The temperature range that was tested was 122°F (50°C) to 149°F (65°C) (Kaleemullah 2006). The study took into consideration, capsaicin content, color, and drying time. The results showed that the optimal

drying temperature was 131°F (55°C). This article is useful to the project if the final solution implements a thin layer drying method.

The experiment titled *Drying of Red Pepper (Capsicum Annuum): Water Desorption and Quality* dried red peppers at different air-drying temperatures. The results of the experiment show that the air drying temperature influenced the final quality of the dried red pepper (Simal 2005). It was also found an optimum range of drying for peppers to be within 122°F (50°C) and 158°F (70°C) (Simal 2005). The information from this experiment will be helpful when the team begins looking at desired temperature ranges for the solution.

The Web site titled *Drying Chili Peppers* was helpful to the team by describing several traditional small scale methods for drying chilies. The team did notice that typically these methods resulted in a moisture content in the chili from 8% to 12%, which is not low enough for the desired process (Sanut). Even though the Web site mentioned that the methods could be adapted to large scale processes, it does not reduce the moisture content enough to be applicable to this project.

Design Specifications

- Reduce fuel consumption of drying process
- Decrease dependence on manual labor
- Meet current production rates
- Simple operation

Design Concepts

The main focus of the fall semester was developing several different concepts that we would present to the client to get feedback. At the end of the fall semester *Spicy Solutions* presented S&S Farms with five design concepts. The five concepts were modification to the current dryers



and burners, modified air flow and temperature, the use of an air-to-air heat exchanger, a continuous flow dryer, and a method of recirculation. These concepts are discussed in more details below. The five concepts do not result in the same process efficiency, and the five concepts vary greatly in cost.

The first concept that was presented was modifying the burners currently in use or modifying the bed depth to increase the efficiency of the process. The current burner used in the Peerless 103 dryer consists of a steel pipe with a hole drilled in the end of the pipe cap to act as an orifice. The current burner would be exchanged for a burner that would have been purchased, for example, Maxon's NP-LE Airflo burner. The Maxon burner has the same Btu/hr rating as the Peerless burner, but the Maxon is a line burner where the Peerless burner is a self-cleaning star burner. Figure 6 is a picture of the Maxon NP-LE burner.

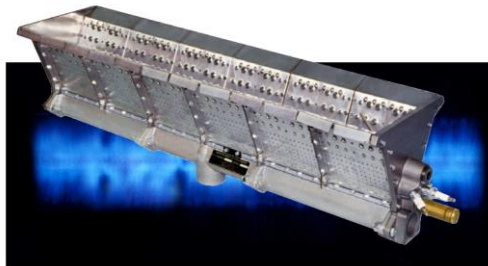


Figure 6. Maxon NP-LE Airflo Burner.

The second part of the current system modification was modifying the depth of the bed. The current Peerless dryers and bins were designed to dry peanuts at 75% capacity. Currently the peanut bins are filled to the top with peppers. Increasing the drying bed depth increases the thermal efficiency of drying by using all of the heated air moisture removal capacity. The increase in bed depth also increases the static pressure of the airflow. As the static pressure increases, the fans efficiency could decrease. This would result in needing a decreased bed depth to have a more efficient process.

The second concept that was presented was modifying the air flow and temperature. By decreasing the temperature and airflow, fuel is not wasted on heating air that is exhausted out of the top of the bed before it has reached a high relative humidity.

The third concept was an air-to-air heat exchanger that would use the air exiting the top of the wagon to warm colder dry air entering the dryer. This method would allow the cold dry intake air to be warmed by the high humidity heated air before it ever reaches the burners. The team proposed three locations for the heat exchanger. The first location was hanging the intake tube from the rafters of the building. The second location was placing the heat exchanger directly on top of the bed. The third location is to permanently place the exchanger in the bins and allow the duct to be connected to the bin, similar to how the dryer connects to the current bins.

The fourth concept that the team presented was a continuous flow dryer. In the continuous flow dryer the peppers are conveyed through different temperature airstreams. Belt dryers can also provide agitation by designing multiple pass dryers. A multiple pass continuous belt drying system can use the concept of recirculation easily by allowing the wet peppers to enter into the top of the dryer and the dry peppers to exit the bottom. The heated air can then be forced from the bottom of the dryer to the top.

The hot dry air passes through the semi-dry peppers to finish the drying process. The air then passes through a bed of wet peppers because it still has the ability to remove moisture. Figure 7 illustrates this process.

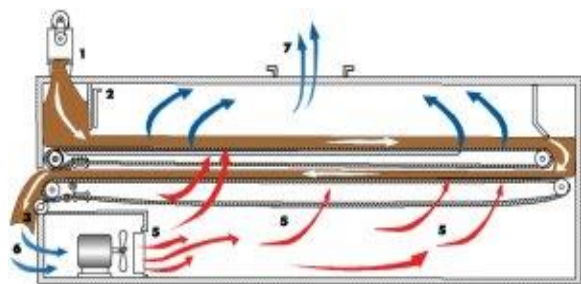


Figure 7. Belt-o-matic Dryer.

The final concept developed in the fall semester was recirculation of the air that is exhausted off the top of the bins. The recirculation concept involves reusing exhaust air from the

bins that has yet to reach saturation. This concept is based on utilizing as much heat as possible from the air. The team proposed two different methods of recirculation of the air. The first was redirecting the air from the top of the bin back into the dryers. The second method was redirecting the exhaust air from the top of the bin into the bottom of neighboring bin.

After the fall semester presentation our sponsor expressed interest in the continuous flow dryer concept that was presented. Once the team had a chance to discuss the idea more with our sponsor we concluded that it would not be cost efficient to purpose a continuous flow dryer; however, if the team was able to present S&S Farms with the proper specifications S&S Farms would be able to construct a dryer based on those specifications. After some initial energy requirement calculations the team also considered recirculating some of the exhaust air to reduce the energy requirement.

Calculations

Since reducing the peppers to a final moisture content of 5% is the main purpose of the process, finding the amount of air that is required to remove the necessary water is a major determining factor of the design. The air requirement was calculated using the temperature and relative humidity of the incoming air and the humidity ratio of the air. The psychometric chart was used to determine the humidity ratio for the air at the inlet of the fan and after the air had been heated.

The first step in performing the calculations was to determine the amount of water that needs to be removed from the peppers per hour. The amount of water that must be removed is based on the difference between the initial and final moisture content. Since the initial moisture content will be changing throughout the season the first calculations were made on the assumed highest moisture content. The next step is to find how much water the air can remove based on



its properties. The relative humidity and incoming temperature were used to determine an initial humidity ratio. The humidity ratio of the air after the heater was found using the desired temperature of the dryer and a relative humidity of 80%. A relative humidity of 80% was chosen as the ideal humidity of the exiting air, so that the air is near saturation at the outlet of the dryer. The difference in the humidity ratios between those two points determines the amount of water that the air can hold. The humidity ratio difference was then multiplied by the specific volume of the incoming air, which was determined from the psychometric chart, and the amount of water that needs to be removed to give the amount of air that is required in cubic feet per minute.

The energy requirement in Btu per minute was then calculated given the required air in cubic feet per minute and finding the latent heat of vaporization for the amount of water that needs to be removed. The amount of energy it would take to heat the required air was found by dividing the change in enthalpy between the two points on the psychometric chart and the specific volume of the incoming air and then multiplying that value by the air requirements. That value only gives the amount of energy that is required to heat the air. Next the latent heat of vaporization was found based on the assumption that it requires 1000 Btu (1,055,056 J) per pound of water that needs to be removed. Those two energy requirements were then added together to determine the total energy requirements.

Since the air requirement will be different depending on the incoming air properties and the incoming pepper conditions, the calculations were calculated for several best and worse case scenarios. The table below shows a summary of the required air flow and energy requirements for four combinations of incoming air conditions. The best and worst conditions that were considered were a cold, humid day, a cold, dry day, a warm humid day and a warm dry day. Those conditions were selected based off a general temperature range for western Oklahoma.



Dryer Temperature (°F)	Incoming Temperature (°F)	Requirements	
		Air (cfm)	Energy (Million Btu/hr)
110	30	39,400-42,200	8.43-8.50
	55	49,600-63,000	6.80-6.97
150	30	25,900-27,000	8.37-8.40
	55	30,300-34,600	7.36-7.41
180	30	19,500-20,200	8.10-8.11
	55	22,300-24,500	7.34-7.39

Table 1. Summary of Air and Energy Requirements

Testing

To determine the effects of different dryer settings and environmental conditions on time required for the peppers to reach the desired moisture content, several drying tests were conducted by the team. *Spicy Solutions* wanted to obtain the use of a dryer that would allow for experiments to test variable temperature, air flow, bed thickness, and humidity. After consulting with Dr. Tim Bowser, a Food Process Engineer for Oklahoma State University’s Food and Agricultural Products Center (FAPC), the team evaluated Dr. Bowser’s jerky dehydrator. (Figure 8).

David Moe, FAPC Pilot Plant Manager, recommended the use of a Proctor & Schwartz variable circulation laboratory dryer (Figure 10). The Proctor dryer would allow experiments to test variable temperature, air flow, bed thickness, and air flow direction.

Jerky Dehydrator

The jerky dehydrator is an insulated wood frame room that allows several mobile baking racks to be rolled in and out. The jerky shack was designed to dehydrate thin beef strips into beef jerky. The jerky shack is capable of drying at temperatures between ambient air temperature and 160°F (71°C). Air temperature is controlled by a hydronic heating system that is supported by a gas fired tank less hot water heater. A large blower is located at the back of the

dehydrator and can be adjusted to operate at three different speeds. The fan circulates the air throughout the dehydrator. It also helps mix the recirculated air with the fresh air inside the dehydrating room.

The humidity inside of the dehydrator is controlled by a Steamist steam generator. The dehydrator was also equipped with an electric scale where the weigh tray was suspended through the ceiling of the dehydrator so that air can easily flow through the material. This particular scale is a Sartorius

and is connected to a laptop computer to record weights every minute. A Fluke data logger monitors the temperature inside the dehydration room. The scale and data logger was very helpful because it allowed us to take measurements without opening and closing the door of the dehydrator, which can cause variations in the dehydrators operating conditions.

The first test that we conducted was a thin bed of peppers which was roughly 1 pepper deep. The jerky dehydrator's temperature and airflow conditions for Test 1 were 108°F (42.4°C) and a fan speed set on high. The air velocity measured through the pepper bed was measured to be 0.49 ft/s (0.15 m/s).

After measuring the range of airflows that the Jerky Dehydrator was capable of producing the team decided higher airflow needed to be tested.

Pepper Rehydration

Although the jerky dehydrator didn't provide a large enough range of airflows, it did allow the team to control and monitor the relative humidity inside the room. The team was able to use the jerky dehydrator as a pepper hydrator by saturating the air inside the room with the



Figure 8. Jerky Dehydrator.

steam generator. This allowed the team to test several other drying conditions because the team had a limited supply of fresh moisture peppers, but had several pounds of naturally dried peppers.

Cabinet Dryer

The Proctor laboratory dryer has a drying air temperature range of ambient to 200°F (93°C) and air flow rates from 100 ft³/min (0.047m³/s) to 900 ft³/min (0.42 m³/s). The dryer did not allow the team to control the humidity within the dryer, but did allow the team to force air from the top or bottom, by adjusting air baffles inside the drying chamber. The trays within the drying chamber are made of



Figure 9. Cabinet Dryer.

metal and were easily removed for weight to be taken. The team decided to use a set of perforated trays that were 36 inches (91 cm) wide and 24 inches (61 cm) long with 1/8 inch (0.32 cm) holes drilled in the bottom to allow air to flow through the bed of peppers. The team performed six test in the Proctor dryer. We evaluated three air temperatures at two different air velocities. Table 2 shows the dryer setting for the six tests performed.

Test	Temperature (°F)	Velocity (m/s)
1	110	1.2
2	110	2.2
3	150	1.2
4	150	2.2
5	190	1.2
6	190	2.2

Table 2. Proctor Dryer Setting

The drying curves were created by weighing the dryer tray every three minutes. When three measurements were the same the team weighed the samples on a 15-minute interval. Figure 11 shows the drying curves from the Proctor drying tests.

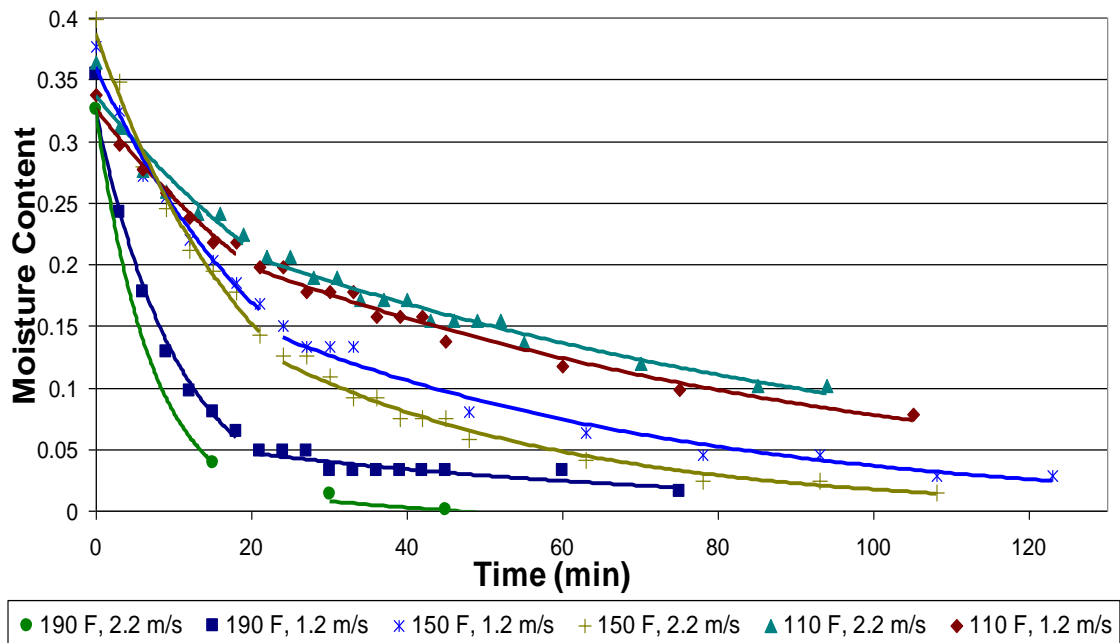


Figure 10. Proctor Drying Tests.

Capsaicin and Dicapsaicin Measurement

Capsaicin and dicapsaicin compose approximately 90% of the desired chemicals extracted from the chili peppers. Capsaicin and dicapsaicin were measured to determine if the amounts of the chemicals were decreased during testing. This information is important, because our client is paid for these chemicals. Any loss would need to be offset by a decrease in processing costs.

The chemicals are extracted from the peppers before they are measured. To extract the chemicals, the peppers are ground into a powder. The stems were removed before grinding the peppers. Next, 200 and 400 mg samples were put into vials. 2 mL of dimethyl formamide was added to the vials. The samples were then heated in a hot plate at 176°F (80 °C) for one hour. The samples were mixed every 15 minutes during the incubation. After one hour of extraction, samples were centrifuged to separate the liquid from the solid. The liquid was removed with a

pipette and saved for analysis. The remaining solid material was used in three more extractions. For each extraction, the above procedures are repeated starting with the addition of 2 mL of dimethyl formamide. The liquid saved from all four extractions was mixed together and put into 2 mL vials. The vials were loaded into the high performance liquid chromatograph (HPLC), which measures the amount of each chemical.

The results of the HPLC are provided by graphing the level of detection vs. time. The areas under the curve are calculated by a computer. Amounts of chemicals are found by comparing the area under the curve for particular peaks of samples with the area under the curve for peaks of a known amount of a standard. The graphs obtained by the HPLC contained peaks that were not well defined. Therefore, some of the data was thrown out for calculating the amount of capsaicin and dicapsaicin. The majority of the peaks were used in the calculation, and provided the data in Table 3.

Table 3. Chemical Measurements

	Capsaicin (PPM)	Dicapsaicin (PPM)
control 200 mg	169	140
dried 200 mg	229	176
control 400 mg	419	207
dried 400 mg	403	290

It was concluded that no significant loss of either capsaicin or dicapsaicin could be found at 108°F (42°C). More measurements of capsaicin and dicapsaicin should be conducted using a new column for the HPLC. These measurements should be from samples dried at a range of temperatures from 104°F (40°C) to 248°F (120°C).

Drying Rates

Moisture Content

The moisture content (M.C.) of the peppers during drying experiments is calculated by the following formula where the M.C. is determined by the mass of water in the peppers divided by the dry mass of the peppers:

$$M.C. = (m - m_{dry}) / m_{dry}$$

The mass of the water in the peppers is found by subtracting the dry mass of the peppers from the mass of the peppers at a particular time. This gives the M.C. of the peppers at that particular time.

Drying Curve

The moisture content of the peppers plotted versus time produced a logarithmic drying curve. The drying curves can be linearized using a logarithmic plot. Therefore, a plot of the natural log of the moisture content vs. time is used to obtain a drying rate. The slope of the line of best fit gives the drying rate.

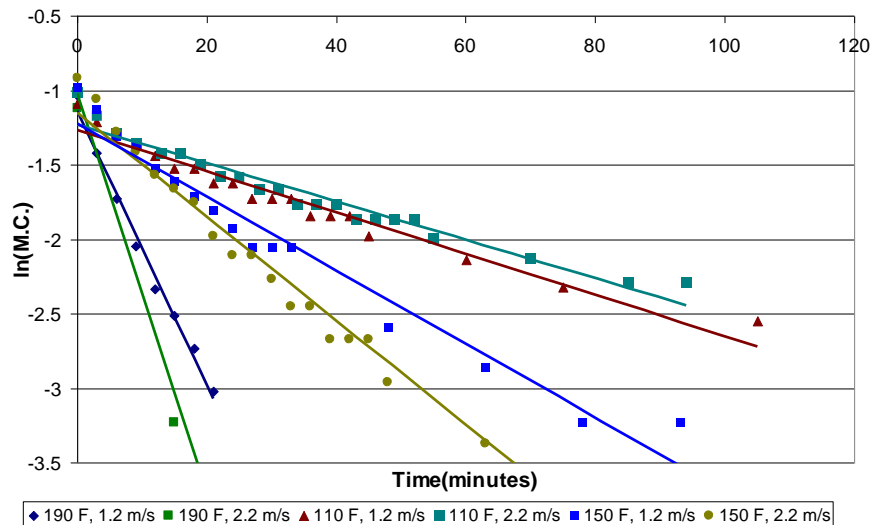


Figure 11. Logarithmic plot of drying curve

The drying rates from the different experiments were compared. This comparison allows for the best drying techniques to be selected. It also helps to put the drying rates from rehydrated peppers into perspective, as the properties of biological materials can change with rehydration. The drying rates for different parameters can be compared to show how the drying rate changes as the parameters change.

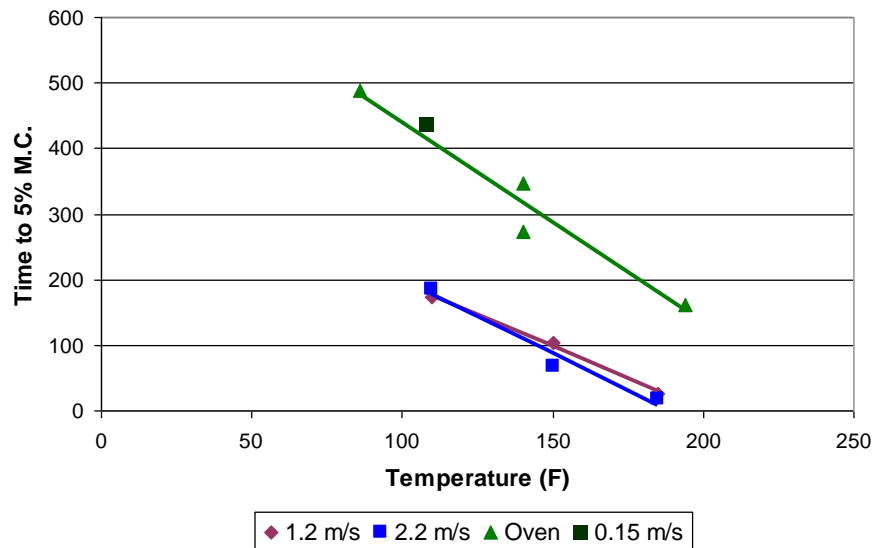


Figure 12. Drying rates for different temperatures. Tests at 1.2 and 2.2 m/s were performed in the cabinet dryer. The test at .15 m/s was performed in the jerky dryer. The convection oven airflow is unknown.

The drying rate increases with temperature, as a larger negative value is a faster drying rate. The air velocity also had an effect. It is important to note that the drying rates obtained at 0.49, 3.9, and 7.2 ft/s (0.15, 1.2, and 2.2 m/s) were from rehydrated peppers, while the drying rates from the oven are from non-rehydrated peppers at a low moisture content.

Estimated Drying Time

The amount of time required to dry the chili peppers based on the drying rate is an important parameter for design. This time is calculated using the drying rates determined from experimentation, and provides for drying from 55% M.C. to 5% M.C. Drying times shorter than

an hour were obtained on the rehydrated peppers at 190°F (88°C). It is assumed the drying time will increase for non-rehydrated peppers.

Design Parameters

Flow rate

A pepper flow rate of 6,000 lb/hr (2700 kg/hr) was used based on client's needs. A volumetric flow rate of 787.5 ft³/hr (22.3m³/hr) was obtained using a measured bulk density.

Temperature

A temperature of 180°F (82°C) was chosen for a drying temperature. The energy requirements based on this temperature were more favorable than other temperatures. Further, the drying rate is also faster at this temperature than the other temperatures tested. This temperature was also chosen to protect the product. Due to the inability to obtain good data on capsaicin and dicapsaicin loss along with concerns expressed by a horticulturalist, a temperature higher than 180°F (82°C) was not chosen.

Airflow

An airflow of 25,000 ft³/min (11.8 m³/s) was chosen based on the calculations at a temperature of 180°F (82°C).

Layer Thickness

A thickness of peppers of one foot (0.30 m) was chosen as the most reasonable. It should provide thin-bed drying characteristics and still be manageable in the dryer.

Belt Area

A belt area of 10 feet (3.0 m) wide by 78.75 feet (24 m) long was chosen. However, this area can be split between three belts, and the belts can be stacked vertically. The stacking of the

belts allows a smaller dryer size, thus increasing the air velocity. Increased air velocity produces shorter drying times.

Air Velocity

The other parameters should provide an air velocity of 1.2 ft/s (0.37 m/s). A higher velocity was desired, however, this value was determined to be acceptable after iterations of parameters were calculated. To obtain a velocity of 3.28 ft/s (1m/s), either the airflow must be almost tripled or the area of the dryer be decreased. Increasing the airflow is expensive and was determined to not be cost beneficial. Decreasing the area of the dryer could be done by dividing the belt area into 10 belts that are stacked vertically, which was determined to be unreasonable. Further, the velocity had less of an effect than other parameters. Finally, U.S. Patent No. 20,070,160,729 stated an air speed of 0.66 ft/s (0.2 m/s) or greater works well for continuous drying. Therefore, the velocity of 1.2 ft/s (0.37 m/s) was accepted.

Retention Time

A retention time of one hour was chosen to meet the needed flow rate and to decrease dryer size and increase air velocity. The longer the peppers are in the dryer, the larger it must be to keep up with the pepper flow rate.

Recommendations

Layout

Spicy Solutions recommends building a triple pass conveyor. Each conveyor should be 10 feet (3.0 m) wide and 27 feet (8.2 m) long which results in a product depth of 1 foot (0.30 m). The bottom conveyor should be 40 feet (12 m) long so the last 10 to 15 feet (3.0 to 4.6 m) of the conveyor is outside of the dryer. The outer section will allow the peppers to cool. Cooling is required so that the peppers do not absorb moisture from the ambient air. The intake air to the



dryer is also drawn through the outer section of the conveyor because it allows the air to increase the air temperature from ambient, and requires less heat to warm the dryer air. The operating temperature of the dryer should be 180°F (42°C). The multiple passes of the conveyor will mix the peppers that will result in more uniformly dry product. The incoming wet peppers, the green arrows, enter in the top left and flow down over the three conveyors. The incoming cold air, the blue arrows, first passes through the dry peppers to assist with cooling and preheating the incoming air. The air then passes through a burner and forced up through the three conveyors and the air exits from the top of the dryer. Figure 16 shows the proposed layout of the dryer.

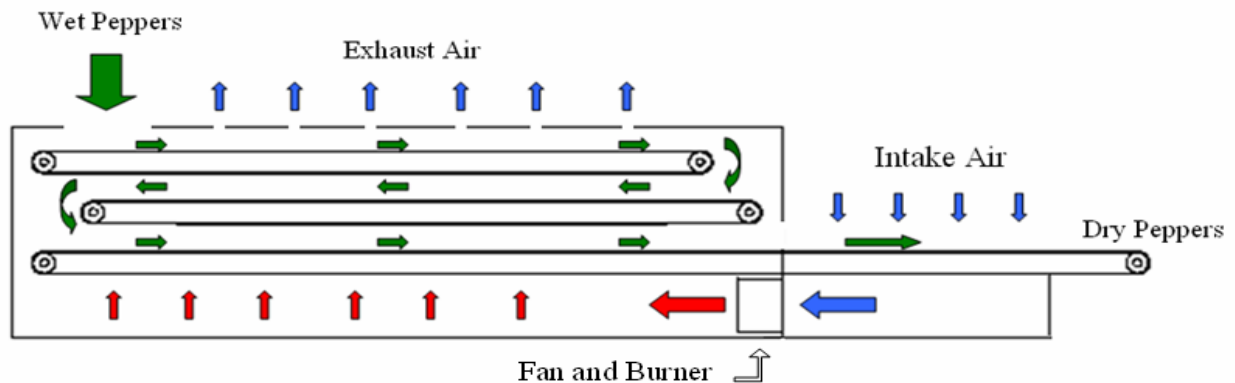


Figure 13. Recommended Dryer Layout

Burners

Spicy Solutions recommends two possible burners. Both options provided the required 7 to 8 million Btu per hour but vary in price.

Maxon NP-LE Burner

The Maxon burner produces 1 million Btu per hour so the dryer would require at least 7 feet of the burner. The burner costs \$1,250 and requires \$10,000 for

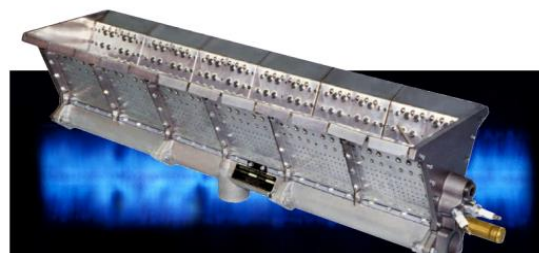


Figure 14. Maxon NP-LE Burner

controllers to control the gas and electric components of the burner.

Hauck Mfg. Co Beta Series Burner

The Beta Series burner provides 4.9 to 8 million Btu per hour. The burner costs 4,500 dollars and requires an additional \$1,500 for the ignition tile and pilot.



Figure 15. Hauck Mfg. Co Burner

Fans

Spicy Solutions is also recommending two possible tube axial fans that provide the required 25,000 to 30,000 cubic feet per minute.

Grainger 42 inch fan

The first recommendation is the Grainger 42 inch fan which provides 24,920 to 33,000 cubic feet per minute depending on the static pressure and costs approximately \$2,700.



Figure 16. Grainger 42 inch tube axial fan

Cincinnati Fan 48 inch fan

The second recommendation provides a range of air flows from 25,300 to 38,700 cubic feet per minute. The Cincinnati fan costs approximately \$2,400.



Figure 17. Cincinnati Fan 48 inch fan

Conveyor

A wire mesh conveyor is the recommended material for the three conveyors of the dryer. The



Figure 18. Wire mesh conveyor

holes in the conveyor allow the air to flow up through the peppers without allowing the peppers to fall through. The total price of the conveyor is approximately \$60,000.

Cost Analysis

Table 4 shows a summary of the costs of each of the components recommended for the continuous flow dryer.

Table 4. Cost Summary of Components

Component	Cost
Conveyors	\$60,000
Fans	\$4,800-\$5,400
Burner	\$6,000-\$12,000
Structural Material	\$15,000
Total	\$85,800-\$92,400

Works Cited

- Ayensu, Akwasi. 1997. Dehydration of food crops using a solar dryer with convective heat flow. *Solar Energy*. 59, 121-126.
- Butts, C.L., & Sanders, T.H.. 2001. Curing Peanuts Using Continuous Flow Dryers.
- Daika. "Peanut Dryer." *Daika*. Available from http://www.advancedryer.com/peanut_dryers.htm. Internet; accessed 11 October 2007.
- Graham, W., L. New, and W. A. Case. 2006. System and method for pulverizing and extracting moisture. U.S. Patent No. 7,137,580
- Graham, W., L. New, and W. A. Case. 2006. System and method for pulverizing and extracting moisture. U.S. Patent No. 7,059,550
- Graham, W., L. New, and W. A. Case. 2006. System and method for pulverizing and extracting moisture. U.S. Patent No. 7,040,557
- GT Mfg., Inc. "Grain Dryers." Available from http://www.gtmfg.com/grain_dryers.html. Internet; accessed 11 October 2007.
- Headly, Oliver. "Medium Scale Solar Crop Dryers for Agricultural Products." *Kenes*. Available from <http://www.kenes.com/Ises.Abstracts/Htm/0053.htm>. Internet; accessed 11 October 2007.
- Kaleemullah, S., & Kailappan, R.. 2006. Modelling of Thin-layer drying kinetics of red chillies. *Journal of Food Engineering*. 76, 531-537.
- Mori, H., T. Hirano, H. Kuhara, A. Okada, S. Yamahara. 2007. Capsinoid-containing dried chili pepper product and method of drying the same. U.S. Patent Application No. 20,070,160,729

- Niles, P.W., E.J. Carnegie, J.G. Pohl, & J.M. Cherne.. 1978. Design and performance of an air collector for industrial crop dehydration. *Solar Energy*, 20, 19-23.
- Peerless. "Peerless Dryers." *Peerless*. Available from <http://www.peerlessmfg.cc/dryers1.htm>. Internet; accessed 11 October 2007.
- Pordesimo, L.O., Li, H., Reddick, B.B., & Habera, L.F.. 2001. Effects of Drying Procedure, Cultivar, and Harvest Number on Capsaicin Levels in Dried Jalapeno Peppers.
- Sanut, John. "Drying Chile Peppers." Available from <http://www.g6csy.net/chile/drying.html>. Internet; accessed 12 October 2007.
- Simal, S., Garau, C., Femenia, A., & Rossello, C.. 2005. Drying of Red Pepper (*Capsicum Annuum*):. *International Journal of Food Engineering*, 1, 1-14.
- SMF Associates. "Blueline Crop Dryers." *Blueline Dryers*. Available from <http://www.bluelinedryers.com/blueline-dryers.htm>. Internet; accessed 11 October 2007.
- Stone, Marvin L., 1982. Modeling of deep bed hop drying. PhD diss. Pullman, Wash.: Washington State University, Program of Engineering Science.

Appendix A

Fall Design Concepts

Design Concepts

Spicy Solutions is presenting S&S Farms with five design concepts. These concepts are discussed in more details below. The five concepts do not result in the same process efficiency, and the five concepts vary greatly in cost.

1. Peerless Dryer Modification
 - a. Modified Burner
 - b. Modified Bed Depth
2. Modified Air Flow and Temperature
3. Air-to-Air Heat Exchanger
4. Continuous Flow Dryer
5. Recirculation
 - a. To Dryer
 - b. To Bin

Concept #1 Peerless Dryer Modification

Spicy Solutions' first concept does not change the mechanics of the current drying process. This concept allows the majority of the equipment currently used to be modified and will continue to be used in the drying process.

Modified Burner

The current burner used in the Peerless 103 dryer consists of a steel pipe with a hole drilled in the end of the pipe cap to act as an orifice. *Spicy Solutions* wants to compare efficiencies of the current burner to the Maxon's NP-LE Airflo burner by speaking with a burner companies and fuel efficiency tests. The Maxon burner has the same Btu/hr rating as the Peerless burner, but the Maxon is a line burner where the

Peerless burner is a self-cleaning star burner. Figure 6 is a picture of the Maxon NP-LE burner.

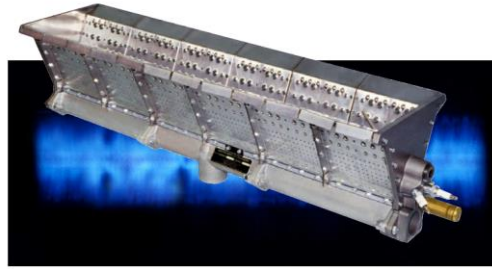


Figure 6. Maxon NP-LE Airflo Burner.

Modified Bed Depth

Peerless dryers and bins were designed to dry peanuts. The peanuts were loaded until the bin was 75% full. Currently the peanut bins are filled to the top. Increasing the drying bed depth increases the thermal efficiency of drying by using all of the heated air moisture removal capacity. The increase in bed depth also increases the static pressure of the airflow. As the static pressure increases, the fans efficiency could decrease. This might result in needing a decreased bed depth to have a more efficient process. *Spicy Solutions* wants to determine the most efficient drying depth for the current Peerless fans.

Concept #2 Modified Air Flow and Temperature

Dr. Marvin L. Stone's research on decreasing the fuel consumption associated with the drying of hops for Washington State University provided *Spicy Solutions* with an alternative idea where air flow and temperature are decreased throughout the drying process. By decreasing the temperature and airflow, fuel is not wasted on heating air that is exhausted out of the top of the bed before it has reached a high relative humidity.

Humidity Sensor

A humidity sensor would be used to measure the relative humidity of the air after it has passed through the peppers. Once the humidity of the exiting air has reached a

certain percentage, the temperature and airflow rate of the air going through the peppers would be altered to maximize drying capabilities of the air.

Burner and Fan Controller

A burner and fan controller would be used to adjust the fan speed and burner temperature, as necessary, through the drying process. Such a controller would eliminate the need for a human operator, thus reducing timing delays and increasing efficiency of the drying system.

Concept #3 Air-to-Air Heat Exchanger

An air-to-air heat exchanger would use the air exiting the top of the wagon to warm the colder dry air entering the dryer. This method would allow the cold dry intake air to be warmed by the high humidity heated air before it ever reaches the dryers burner. To gain the most efficiency, the building must be enclosed, so the exhaust air is forced around the intake tubes and not blown directly into the environment by the wind.

The air-to-air heat exchanger can be placed in three locations. The first location allows the intake tube to hang from the rafters of the building. This allows the bin to move in and out without moving the heat exchanger. The second location is placing the heat exchanger on top of the drying bed. This option requires the operator to remove each exchanger before the bin can be moved. The third location is to permanently place the exchanger in the bins and allow the duct to be connected to the bin, similar to how the dryer connects to the current bins.

Locating the heat exchanger in the building's rafters requires no modification the current dryer bins. The only ducting needed for this set-up is to the dryer's intake. Locating the heat exchanger on top of the drying bed requires flexible tubing that can be moved or lifted off the bin

as easily as possible. Permanently locating the heat exchanger inside the drying bin requires additional ducting to be connected to the drying bin that is flexible and can be removed easily.

Concept #4 Continuous Flow Dryer

In the continuous flow dryer the peppers are conveyed through different temperature airstreams. Belt dryers can also provide agitation by designing multiple pass dryers. A multiple pass continuous belt drying system can use the concept of recirculation easily by allowing the wet peppers

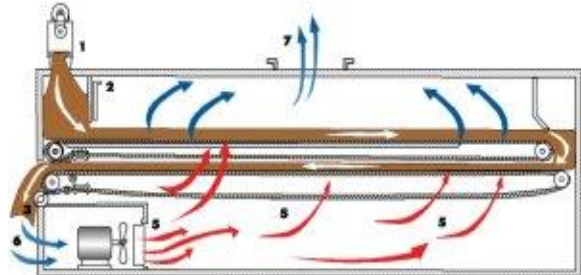


Figure 7. Belt-o-matic Dryer.

to enter into the top of the dryer and the dry peppers to exit the bottom. The heated air can then be forced from the bottom of the dryer to the top. The hot dry air passes through the semi-dry peppers to finish the drying process. The air then passes through a bed of wet peppers because it still has the ability to remove moisture. Figure 7. illustrates this process.

Designing a dryer that is capable of drying at the same rate as the traditional drying system is crucial. For this design, it would be ideal for the dryer's capacity to be more than what is currently being produced to accommodate the future technological advances in the growing, milling and harvesting processes.

Concept #5 Recirculation

Air can hold a certain amount of moisture before it reaches 100 percent relative humidity, a condition known as saturation. The amount of moisture air can hold depends on the temperature of the air, hotter air can hold more moisture than colder air. Thus, heating the air that is passed through the peppers allows for more moisture to be removed before the air reaches saturation. Figure 8 illustrates how the relative humidity of the exhaust air from the bins

decreases as the peppers dry. As the drying process proceeds, the exhaust air from the bins has the ability to absorb more moisture. The recirculation concept involves reusing exhaust air from the bins that has yet to reach saturation. This concept is based on utilizing as much heat as possible from the air. Doing so should decrease the amount of natural gas needed to dry the peppers, thus reducing cost. Two methods were developed: recirculation to dryer and alternating bin recirculation.

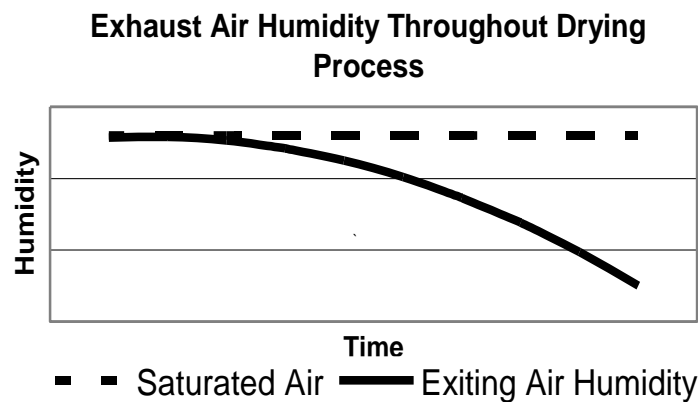
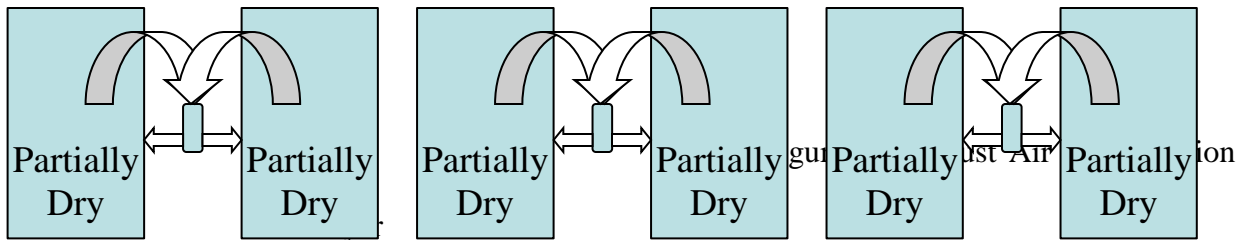


Figure 8. Air Humidity of Exhaust Air from Bin Throughout Drying Process

To Dryer

The recirculation to the dryer is done by conveying exhaust air from the bins back into the dryer. The air can be conveyed by an air duct. This material could be the same flexible material used in the dryer air ducts. A metal or hard plastic could also be used. The ducting would be suspended from the frame of the roof over the bins. The frame of the roof would need to support the weight of the ducting in order to suspend it. The fan from the dryer will create suction to move the air through the ducting. Figure 9 illustrates this method. It shows a dryer blowing air into two bins and the air exhaust from the bin blowing back into the air intake of the dryer.



Another unknown is whether recirculated air will need to be exhausted to the environment and new outside air be added to the recirculation. This depends on what point in the drying that the recirculation begins. As the air is recirculated, it is heated to a higher temperature, increasing its capacity to hold moisture. The even hotter air will have a lower relative humidity. The relative humidity will need to be below the peppers moisture content to dry them.

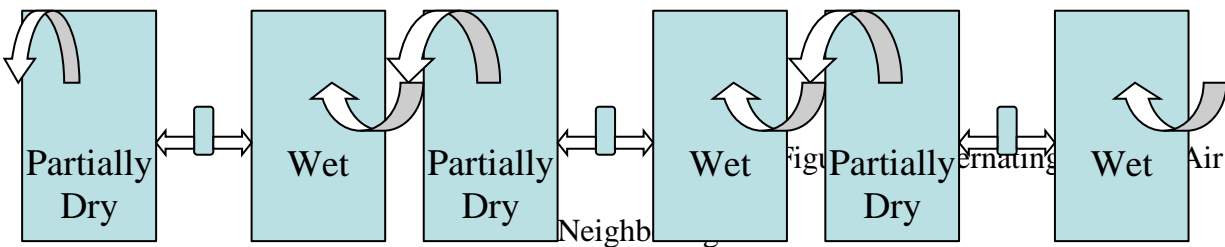
Both bins on the dryer should be started close to the same time, thus causing the peppers in the bins to reach a particular humidity near the same time. If both bins reach the same relative humidity at the same time, the recirculation will be more efficient. If the relative humidity of the exhaust air of the bins is different, one bin would continue to dry past the recirculation start point until the second bin reaches the recirculation start point. In this case, heated air that could be recirculated is lost to the environment.

It could be possible to start the recirculation of the bins independent of each other. The method of handling the airflow would become more difficult while only one of the two bins is being recirculated. It would be desirable for half of the airflow into the dryer to come from the exhaust of the recirculated bin and half to come from outside air. Without even airflow into the dryer from these two areas, the airflow would likely slow significantly in the bin where recirculation has started. This condition would likely accelerate drying in the lagging bin, which may be a benefit. However, it causes an

unknown in the recirculated bin and may lead to condensation in this bin. The condensation could drip onto the peppers and increase their moisture content.

To Bin

Another method of recirculating air consists of alternating the direction of airflow between neighboring bins. The exhaust air of a partially dry bin would be added to the airflow entering the neighboring wet bin. When bins are loaded with wet peppers, they are placed at ever other bin location to create an alternating pattern of partially dry and wet bins. Figure 10 illustrates the layout of the bins and the direction of air flow. Once the bin that was partially dry reaches the desired moisture content, it will be removed and a bin full of wet peppers will replace it. At this point, the airflow will need to be reversed, as the formerly wet bin is now partially dry.



Reversing the airflow can be accomplished by reversing the ducting. This would be easiest if the ducting were suspended from the roof frame. The ducting could be on a rotating boom, allowing it to be swung from one bin to the neighboring bin. A fan will need to be added to force the air from the top of the partially dry bin to the bottom of the wet bin. The fan can be placed between the two bins involved in the recirculation. A frame could be used to hold the fan in place, likely four to six feet above the ground. More ducting will carry air from the fan to the neighboring wet bin. This should be a reversible piece that can alternate between the two bins.

This method will cause more of the air to reach saturation. However, whenever one bin is nearly dry, the other bin receiving its exhaust air will be partially dry. Although the air leaving the nearly dry bin will aid in drying the partially dry bin, it will not reach saturation.

Appendix B

Sample Calculations

Sample Calculations

Pepper Conditions:

Amount (lb/hr):
Initial Moisture Content: 55%
Final Moisture Content: 5%
Water that needs to be removed (lb of water): 2129

Incoming Air Conditions:

Temperature: 30 °F
Relative Humidity: 50%
Specific volume (ft³/lb): 12.39
Humidity ratio (lb water/lb of dry air): 0.0017
Enthalpy (Btu/lb of dry air): 9.42

Dryer Conditions:

Temperature: 180 °F
Relative Humidity: 80%
Humidity ratio (lb water/lb of dry air): 0.0235
Enthalpy (Btu/lb of dry air): 47.09

Water that can be removed (lb of water/lb of dry air):

$$\text{Water} = 0.0235 - 0.0017 = 0.0218$$

Amount of air required (ft³/min):

$$\text{Air} = \frac{\text{Water} * V_{sp}}{\text{Capacity}}$$
$$\text{Air} = \frac{2129.03 * 12.39}{0.0218 * 60} = 20167$$

Amount of energy required (Btu/hr):

$$\text{Heat}_{sensible} = \frac{\Delta H}{V_{sp}} * \text{Air} * 60$$
$$\text{Heat}_{latent} = \text{Water} * 1000$$
$$\text{Energy} = \text{Heat}_{sensible} + \text{Heat}_{latent}$$
$$\text{Heat}_{sensible} = \frac{47.09 - 9.42}{12.39} * 20167 * 60 = 3678890$$
$$\text{Heat}_{latent} = 2129.03 * 1000 = 2129030$$
$$\text{Energy} = 3678890 + 2129030 = 5807920$$

Specific volume, humidity ratio, and enthalpy were obtained from a psychometric chart

Appendix C

Safety Analysis Report

Abstract

In this Failure Modes and Effects Analysis we covered an efficient process for drying pharmaceutical grade chili peppers. The system was considered to be the drying process and we analyzed the drying oven as a subassembly, broken into components, such as the motor, fan, conveyor belt ext. The most dangerous hazard discovered was the gas line valve, the malfunction of this component was determined to cause the worst damage. Guards such as monitor devices, inspection procedures, and physicals guards were noted.

Scope

This was an analysis of the drying oven as a subassembly, the components of the subassembly included, the gas valve, motor, conveyor belt, and the fan. Only failure modes for that component were analyzed no failure of components within said components were looked into. Targets used were equipment, people, product and downtime. Hazards to the environment were either ruled out or nonexistent. Processes and equipment used in conjunction with this oven were not analyzed.

System: Pepper drying process
 Subsystem: Dryer
 Probability Interval: 20 years

SPICY SOLUTIONS
FAILURE MODES AND EFFECTS ANALYSIS

Date: April 23, 2008
 Prep. By: Jeff Dunkel
 Nick Messenger

IDENT. NO	ITEM/ FUNCTIONAL IDENT.	FAILURE MODE	FAILURE CAUSE	FAILURE EFFECT	T A R G E T	FAILURE EFFECTS			ACTION REQUIRED/ REMAKS
						SEV	PROB	RISK CODE	
SS.01	GAS VALVE	OPEN	BROKEN SPRING	BURNER OVERHEATING; UNABLE TO SHUT OFF BURNER	P R E	I II III	E	3	REGULARLY INSPECT
		CLOSED	CORROSION/ STUCK	NO FUEL TO CREAT HEAT	T	II	E	3	
		LEAK	CORROSION	FUEL RELEASED IN AIR/EXPOSION HAZARD	P E R T	I II III III	E E E E	2 3 3 3	
SS.02	MOTOR	TO FAST	TO MUCH CURRENT	DOES NOT DRY PEPPERS	R T	II I	C C	2 3	MONITOR THE SPEED
		TO SLOW	NOT ENOUGH CURRENT	PEPPERS BURN	R T	II III	C C	2 3	MONITOR SPEED
		NO MOVMENT	NO CURRENT/ MOTOR MALFUNCTION	DOES NOT MOVE CONVEYER	R T	II III	C C	2 3	
SS.03	FAN	BENT BLADE	NOT EVNOUGH AIR MOVEMENT	NOT ENOUGH AIR FLOW	R T	III III	C C	3 3	MONITOR AIR FLOW
		BROKEN BLADE	NOT ENOUGH MOVEMENT/ THROWN BLADE	NOT ENOUGH AIR FLOW; BLADE CUTS EMPLOYEE	P R T	I III III	C C C	2 3 3	PLACE GUARD OVER FAN
SS.04	HEATER	STUCK ON	TO MUCH HEAT	BURNS PEPPERS; BURN HAZARD	P R T	II III III	E E E	3 3 3	MONITOR HEAT; EMERGENCY SHUTOFF VALVE



Findings

During the analysis of this process we discovered a few hazards. Personnel shall not be exposed to a risk code of 2 or 3. The hazard of a natural gas leak poses great risk, if there were a gas leak contained well enough to reach the Lower Explosive Level along with and pilot source an explosion could occur. The motor poses a threat to the peppers, if it were to operate at slow speeds the product could be burned and ruined. The fan could cause a mishap if it lost a blade may harm personnel. May the conveyor belt were to break the peppers could clog up producing a fire hazard.

Recommendations

Most of the hazards found can be mitigated with minimal safeguards. A guard should be placed around the fan to stop the escape of the blades should they break. A sensor should be connected to the conveyor stopping the heater should it break. The heat in the oven should be monitored and connected to a switch if the maximum heat is exceeded. A voltmeter should be connected ensuring enough electricity is getting to the motor to ensure proper speed.

Severity of Consequences	Probability of Mishap**					
	F Impossible	E Improbable	D Remote	C Occasional	B Probable	A Frequent
I Catastrophic					1	
II Critical				2		
III Marginal			3			
IV Negligible						

Risk Code	1	2	3
Actions	Imperative to suppress risk to lower level	Operation requires written time-limited waiver endorsed by management	Operation
NOTE: Personnel must not be exposed to hazards in risk zones 1 and 2			

Appendix D

Sales Literature



Design of an Efficient Drying System

Kyle Dollins

Becca Hoey

Michael Matousek

BAE 4023

Overview

- Problem Statement
- Sponsor Information
- Current Process
- Fall Design Concepts
- Concept Selection
- Calculations
- Testing
- Design Recommendations



Problem Statement

Develop a time and cost effective drying method to reduce the overhead associated with the increasing price of natural gas by designing a continuous flow dryer.



S & S Farms

- Located in Hinton, Oklahoma
- 1200 acres of super hot chili peppers
- Used in the pharmaceutical industry
- Hand transplanted
- Mechanically harvested



Problem Introduction

- Minimize fuel consumption
- Reduce moisture content, must be 5%
- Initial moisture content ranges between 30-60%
- Process 1.7 million pounds per season
- Averages 60,000 pounds per day



Current Process

- Peanut wagons
- Peerless 103 dual 3-phase dryers
- Open sided barns open to the environment
- Natural gas burners
- Peppers remain in field as long as possible
- Milled into a powder
- Bagged and shipped



Design Requirements

- Reduce fuel consumption of drying process
- Decrease dependence on manual labor
- Meet current production rates
- Simple operation



Proposed Concepts

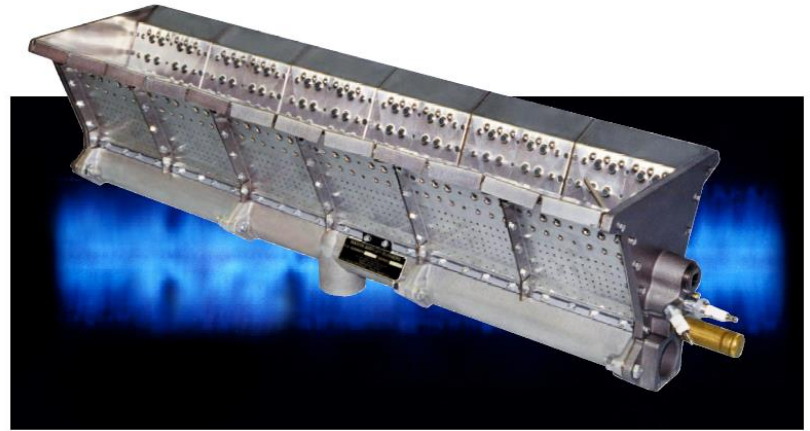
- Peerless Dryer Modification
 - Modify Burner
 - Modify Drying Bed Depth
- Modifying Air Flow and Temperature
- Air-to-Air Heat Exchanger
- Continuous Flow Dryer
- Recirculation



Concept #1

Peerless Dryer Modifications

- Uses majority of current equipment
- Modify Burner
 - Increase air temperature and burner efficiency
- Modify Bed Depth
 - Increase fuel efficiency



<http://www.maxoncorp.com/Files/pdf/B-lb-nple.pdf>

Concept #1 Summary

- Main Advantages
 - Current Drying Bins
 - Decreased fuel consumption
- Associated Cost
 - \$800 - New Burner
 - \$200 - Side Board

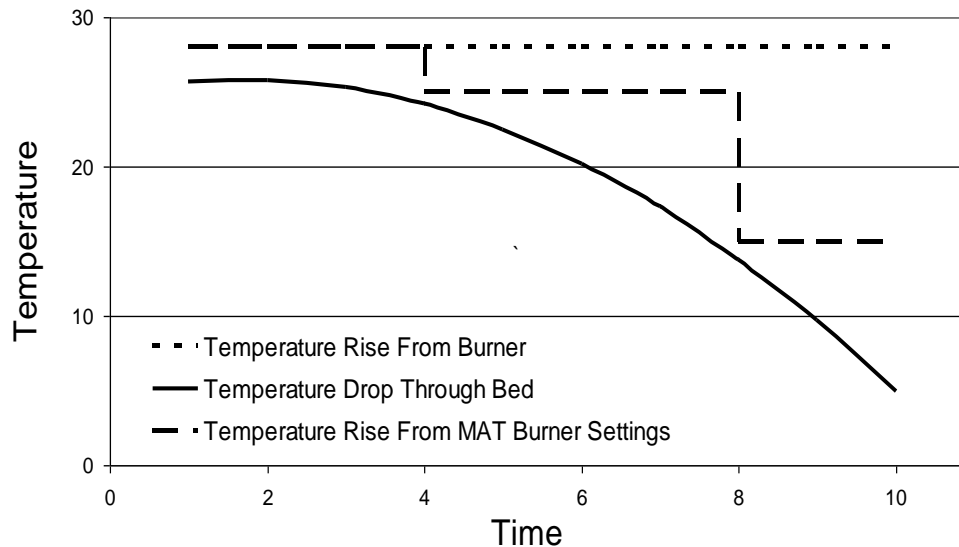


Concept # 2

Modulation of Airflow and Temperature

- As drying process progresses
 - Decrease air temperature
 - Decrease airflow

General Explanation of Modulation of Airflow Temperature



Concept # 2 Summary

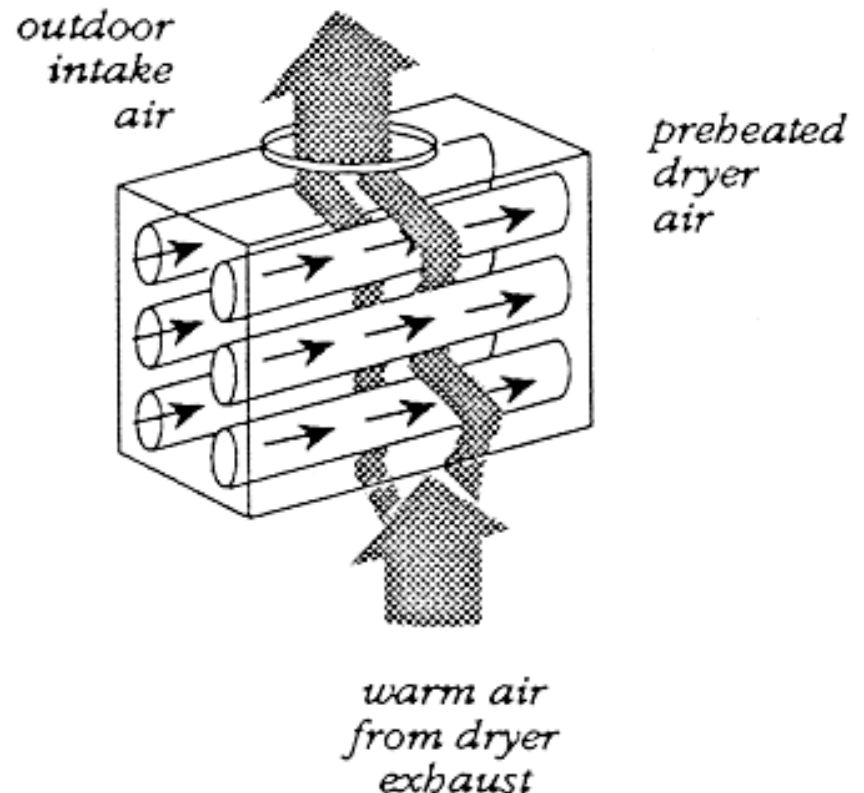
- Main Advantage
 - Decrease in fuel consumption
- Associated cost
 - \$800 – New burner
 - \$6,000 – Burner controller
 - \$200 – Sensors



Concept #3

Air-To-Air Heat Exchanger

- Pre-heat dryer's intake air supply
- Extract heat from dryer's exhaust air
- Intake tubes above drying bins
- Enclosed building



Concept # 3 Summary

- Variation in exchanger placement
 - Above bins
 - Top of peppers
 - In peppers
- Associated Cost
 - \$5,000 - Enclosing building
 - \$5,000 - Air ducts



Concept #4

Continuous Flow Dryer

- Decrease the handling of peppers
- More complex
- High capital cost



<http://www.belt-o-matic.com/Documents/Belt-o-matic.pdf>



Concept # 4 Summary

- Can be integrated into current continuous milling process
- Associated Cost
 - \$500,000 – Dryer
 - Custom built
 - Food grade
 - Purchased from vendor



Concept #5

Recirculation

- Make use of exhaust air currently wasted
- Two recirculation concepts
 - 1st concept
 - Start recirculation once peppers partially dry
 - Convey air exiting bins back into the dryer
 - 2nd concept
 - Convey air exiting partially dry bin to wet bin
 - Saturate air before releasing into atmosphere



Concept #5 Summary

- 1st Method
 - Associated cost per dryer
 - \$225 – duct work
 - \$200 – sensors
- 2nd Method
 - Associated cost per dryer
 - \$325 – fan
 - \$225 – duct work
 - \$200 – sensors



Cost Estimates

Concept	Cost
Peerless Dryer Modification	\$1,000/dryer
Modified Airflow and Temperature	\$7,000/dryer
Air-To-Air Heat Exchanger	\$450/dryer
Continuous Flow Dryer	\$500,000
Recirculation (into dryer)	\$425/dryer
Recirculation (alternating)	\$750/dryer



Concept Selection

- Sponsor chose continuous flow dryer
 - Easily integrated into current milling process
- Build rather than buy
 - Greatly reduce the cost
- Define design specifications



Calculations

- Based on:
 - 60,000 lbs/day
 - 10 hours/day
 - Target drying time 1 hour
- Amount of water that needs to be removed from the peppers
- Amount of air required
- Amount of energy required
 - Latent Heat
 - Sensible Heat



Calculations

- Amount of water that needs to be removed per hour

$$\textit{Water} = P_{55} - P_5$$

$$P_{\textit{wet}} = P_{\textit{dry}} (M.C. + 1)$$

P_{55} = weight of peppers at 55% moisture content (lbs)

P_5 = weight of peppers at 5% moisture content (lbs)

M.C. = moisture content



Calculations-Air requirement

- Amount of air required to remove the water (ft³/min)

$$Air = \frac{Water * V_{sp}}{Capacity * 60}$$

V_{sp} = Specific volume of incoming air (ft³/lb)

Capacity = moisture holding capacity of the air (lb of water/lb of air)



Calculations –Energy Requirements

- Sensible Heat: required to increase temperature

$$Heat_{sensible} = \frac{\Delta H}{V_{sp}} * Air * 60$$

ΔH = change in enthalpy (Btu/lb)

- Latent Heat: heat required to vaporize water

$$Heat_{latent} = Water * 1000$$

- Total Energy:

$$Energy = Heat_{sensible} + Heat_{latent}$$



Calculations Summary

Dryer Temperature (°F)	Incoming Temperature (°F)	Requirements	
		Air (cfm)	Energy (Million Btu/hr)
110	30	39,400-42,200	8.43-8.50
	55	49,600-63,000	6.80-6.97
150	30	25,900-27,000	8.37-8.40
	55	30,300-34,600	7.36-7.41
180	30	19,500-20,200	8.10-8.11
	55	22,300-24,500	7.34-7.39

Assumptions:

Processing 6,000 lbs/hr.

Relative Humidity: 30%-50%

Initial moisture content = 55%

Burner Efficiency: 70%



Testing

- Calculations based on psychometric data of free water
- Water must diffuse through pepper
- Find drying rates
- Equipment
 - Jerky Dehydrator
 - Cabinet Dryer
 - Oven



Jerky Dehydrator

- Insulated wood frame room
- Designed to dehydrate thin beef strips into beef jerky.
- Temperature range from ambient to 160° F
- Capable of reaching 100% humidity
- Not capable of producing high air flow



Rehydration

- Peppers needed to be at a higher moisture content for testing
- Rehydrating using the dehydrator
- Saturated the air inside the dehydrator, forcing the peppers to absorb the moisture

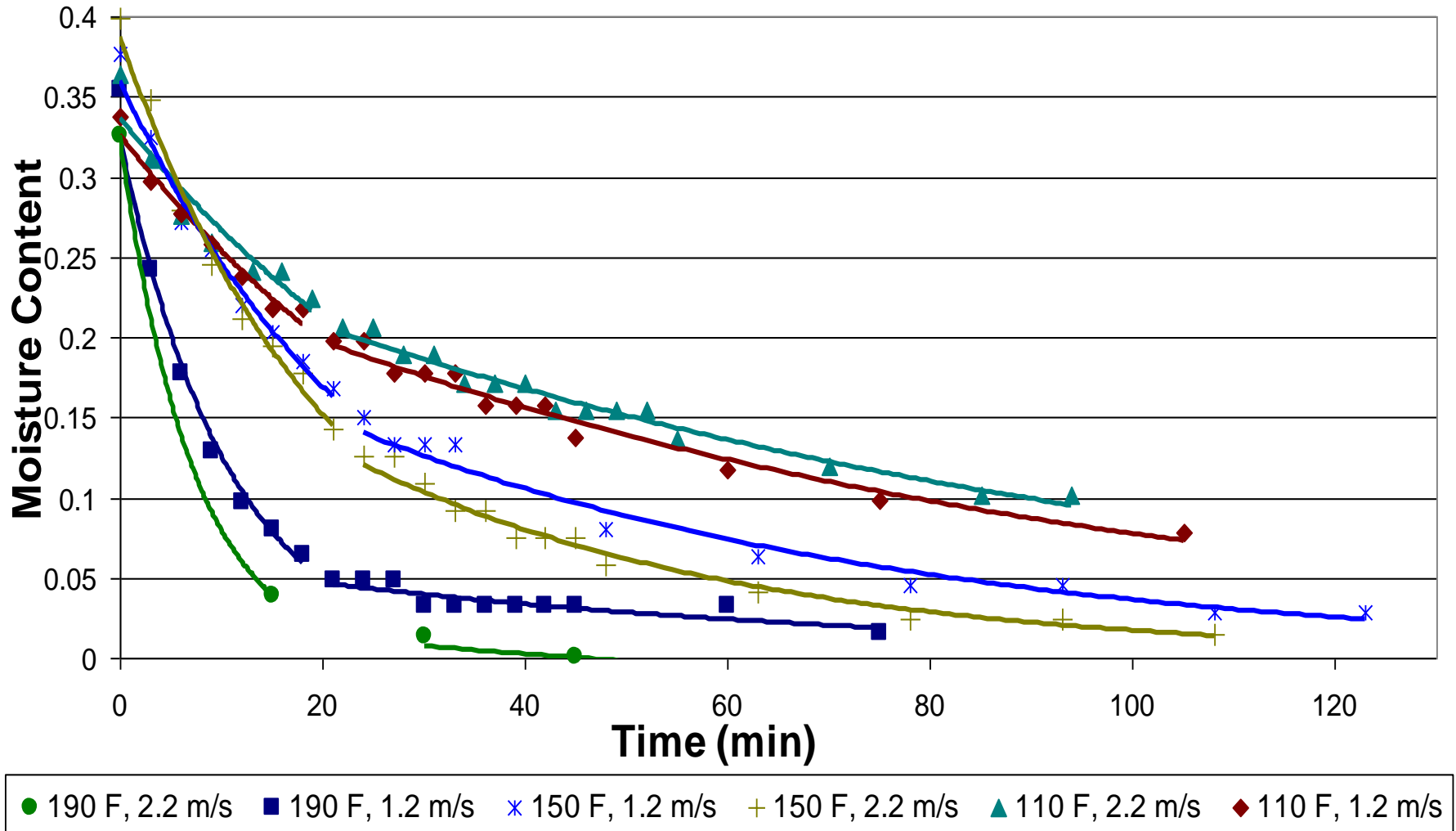


Cabinet Dryer

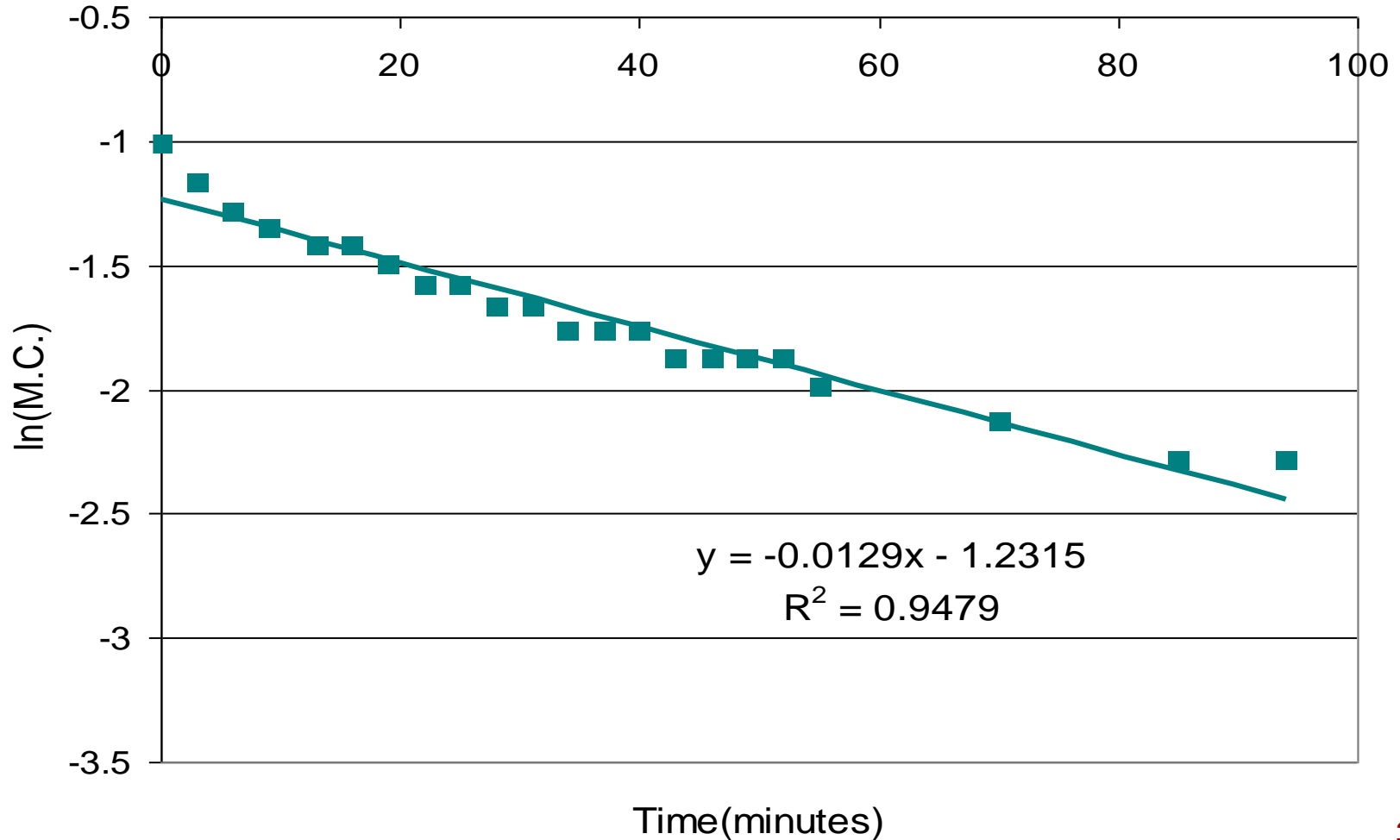
- Used Proctor laboratory dryer
- Perforated trays simulated a perforated conveyor
- Test Conditions
 - 3 Temperatures (°F)
 - 110, 150, 180
 - 2 Air flows (m/s)
 - 1.2, 2.2



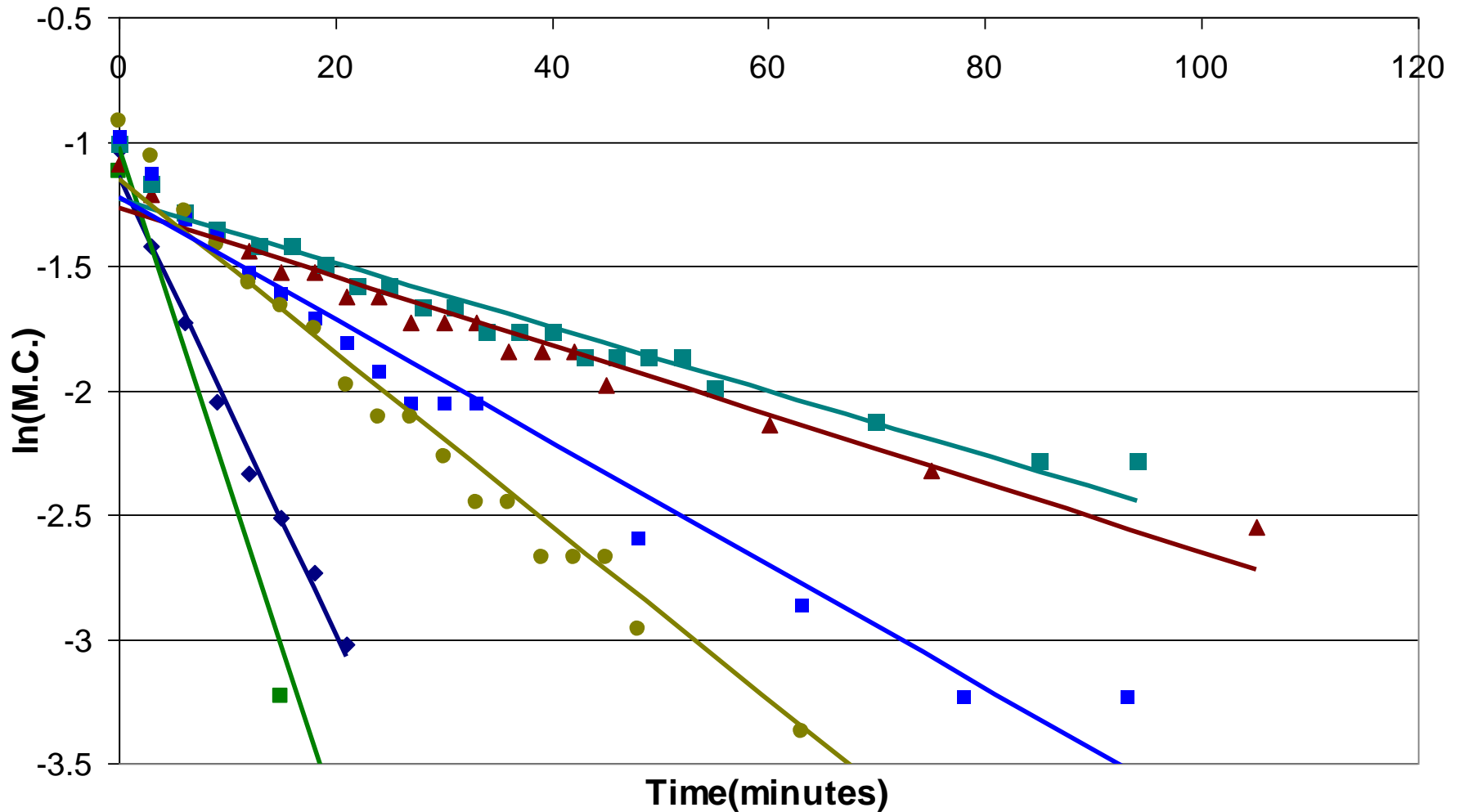
Cabinet Drying Results



Determination of Drying Rate

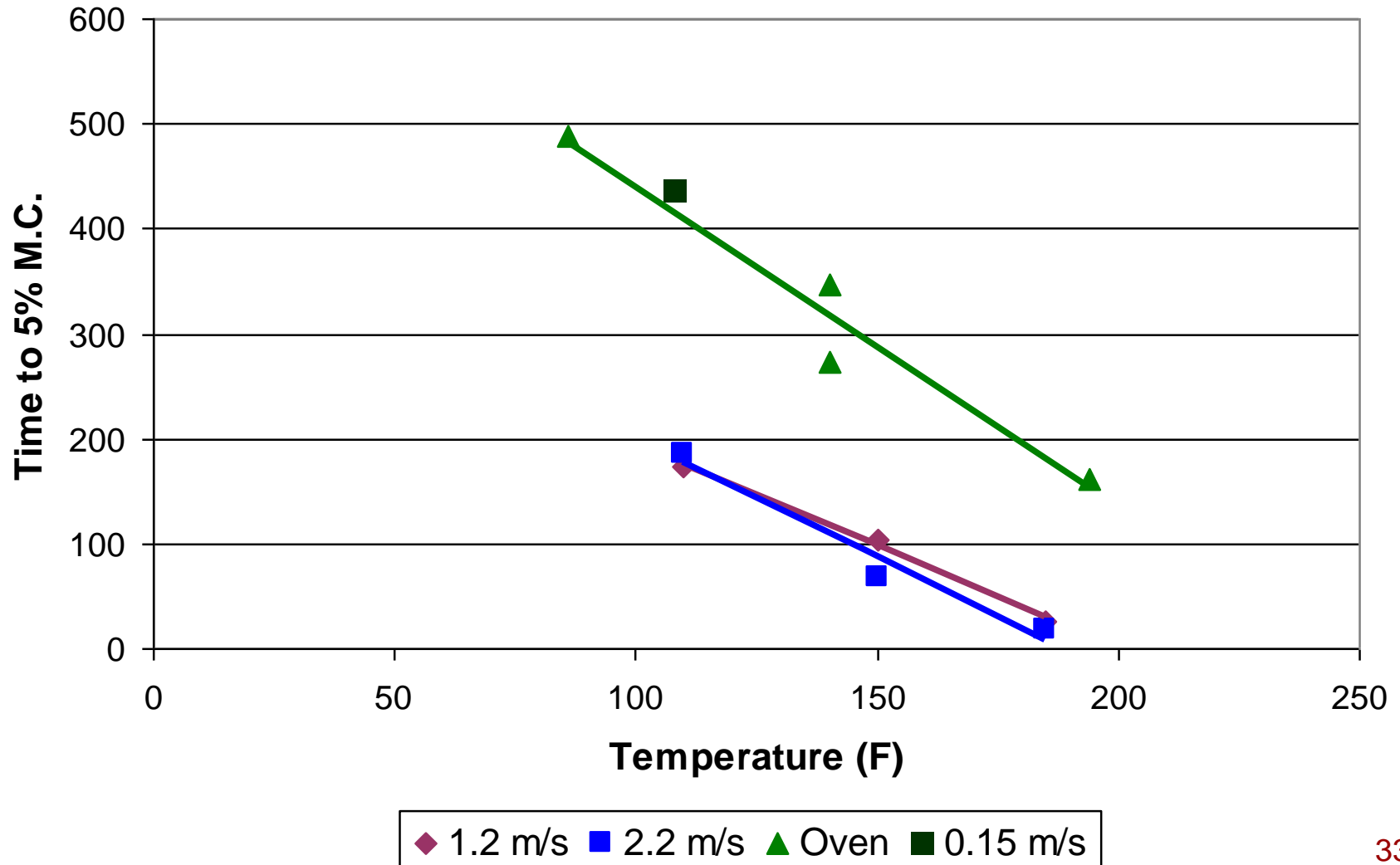


Drying Rates



◆ 190 F, 1.2 m/s ■ 190 F, 2.2 m/s ▲ 110 F, 1.2 m/s ■ 110 F, 2.2 m/s ■ 150 F, 1.2 m/s ● 150 F, 2.2 m/s

Effects on Drying Time



Capsaicin and Dicapsaicin

- Valuable product
- Theoretical degradation – 536°F
- Need to check for diffusion loss
- Testing
 - Solvent removes capsaicin and dicapsaicin from peppers
 - HPLC measures amounts of chemicals
 - Better data desirable – bad peaks



Capsaicin and Dicapsaicin Measurement

Average PPM		
	Capsaicin (PPM)	Dicapsaicin (PPM)
Ambient (200 mg)	169	140
108°F (200 mg)	229	176
Ambient (400 mg)	419	207
108°F (400 mg)	403	290



Design Specifications

- Rate – 6,000 lb/hr
 - Defined by process requirements
- Airflow – 25,000 ft³/min
 - Defined by psychometric calculations
- Temperature - 180°F
 - Defined by drying rates

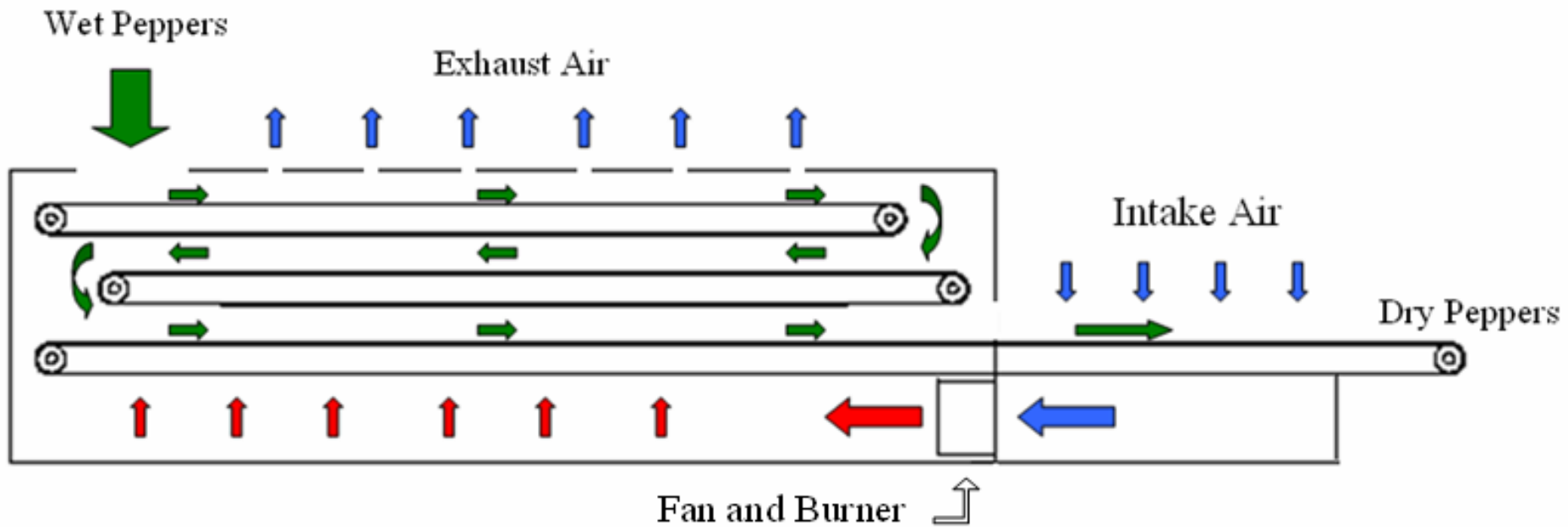


Layout Recommendation

- Triple pass conveyor
 - Help with mixing of the product
 - 10 feet wide and 80 feet total length conveyor
 - Product thickness of 1 foot
 - Three 27 foot conveyors
- Operating temperature of 180 °F
- Operating Belt Speed of 2 ft/min

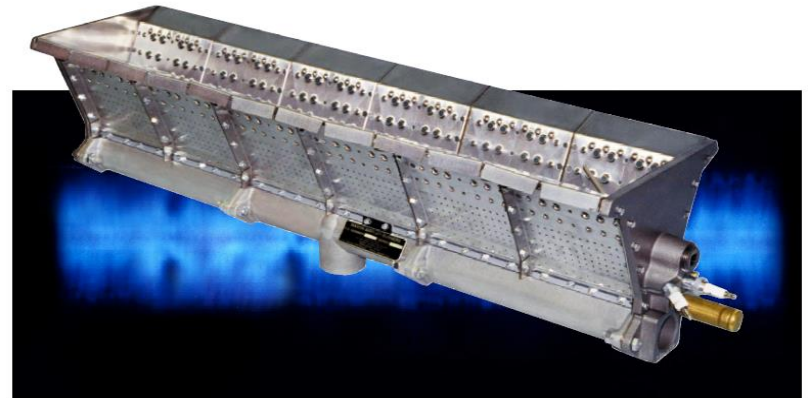


Dryer Set-up



Burner Recommendations

- Maxon NP-LE Burner
 - 1 million btu/ft of burner
 - Need 6 or 7 feet
 - \$1,250 for burner
 - \$10,000 for controllers for gas and electrical system
- Hauck Mfg.Co.
 - 4.9 to 8.8 million btu/hr
 - \$4,500 for burner
 - \$1,500 for ignition tile and pilot



<http://www.maxoncorp.com/Files/pdf/B-lb-nple.pdf>



<http://hauckburner.thomasnet.com/item/gas-burners/bbg-gas-beta-burner/pn-1020?&seo=110>

Fan Recommendations

- Grainger 42 inch tube axial fan
 - Provides 24,920 to 33,000 cubic feet per minute
 - \$2,700
- Cincinnati fan 48 inch tube axial fan
 - Provides 25,300 to 38,700 cubic feet per minute
 - \$2,400



<http://www.grainger.com/Grainger/items/7F877>



<http://www.cincinnati-fan.com/tube-axial-fans.htm>



Conveyor Recommendations

- Wire Mesh Conveyor
 - Holes in mesh
 - Allows air flow through dryer bed
 - Efficient conveying
 - Roller chain
 - Low horsepower requirement
 - 14 Gauge Rod
 - 16 Gauge Spiral



Cost Analysis

Component	Cost
Conveyors	\$60,000
Fans	\$4,800-\$5,400
Burner	\$6,000-\$12,000
Structural Material	\$15,000
Total	\$85,800-\$92,400



Estimated Energy Savings

- Current Natural Gas Cost
 - \$150,000/Season
- Continuous Flow Dryer
 - \$15,500-\$17,500/Season
 - Estimated 70% dryer efficiency
- Savings
 - \$134,500-\$132,500



Acknowledgements

We would like to thank the following people for their help and support:

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- S & S Farms
- Dr. Paul Weckler
- Dr. Tim Bowser
- Dr. Marvin Stone
- Dr. Carol Jones
- Dr. Niels Maness
- Donna Chrz
- David Moe



Questions?





Design of an Efficient Drying System

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Prepared for S & S Farms

BAE 4012

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Problem Introduction

Dean Smith, of S & S Farms in western Oklahoma, is a producer of super-hot chili peppers for use in the pharmaceutical industry. His peppers are used for a variety of different products, including Icy Hot and pepper spray. Before processing and shipping his peppers he must reduce the moisture content to 5 %. The goal of *Spicy Solutions* is to develop a time and cost effective drying method to reduce the expense associated with the increasing price of natural gas, by improving the existing or proposing an alternative drying process.

The current drying process consists of peanut wagons to hold the peppers, fifteen Peerless 103 dual 3-phase dryers that have natural gas burners to heat the air, and a blower that forces the air into the false bottom of the peanut wagon. The peanut wagons are placed under open-sided barns that are exposed to the environment. Currently the dryers raise the ambient air temperature 20°F to 30°F. The current drying time for the peppers ranges from 48 hours at the beginning of the drying season to about 18 hours at the end of the season. The peppers remain in the field on the plant for as long as possible which allows them to dry naturally, thereby reducing the additional energy required to dry them. After they are harvested, they are stored in a barn until they are placed in the peanut wagons for drying. After the peppers have been dried to the desired moisture, they are milled into a powder before being shipped off to the pharmaceutical companies.

For our project, the process must accommodate a total of 1.7 million pounds of peppers per year, and approximately 60,000 pounds per day. A main limitation of our project presented by the client is reducing the amount of natural gas used, which will lower the cost of the process. The current milling process outlines several limitations, including the peanut wagons must be easily accessed and transported, and the drying time of the peppers must be able to keep up with



the milling process. The peanut wagons must be able to be moved from the drying location to the central barn for milling and reloading. The peppers need to be processed in a timely manner to maintain the speed of the milling process and reduce the chance of spoilage.

Spicy Solutions would like to have a final design that is easy to implement and maintain. We would like to develop a solution that would be easy to implement to reduce problems associated with the incorporation of our solution. Reducing the maintenance will reduce the labor cost and the possibility of slowing the process.

Previous Work

Patents

Spicy Solutions started researching patents to determine what was in use and if our design ideas would infringe on existing patents. We found several patents on the topic, but none presented much concern. Below is the team's understanding of the patents that were found.

US Patent Application No. 20,070,160,729 Capsinoid-Containing Dried Chili Pepper Product and Method of Drying the Same Date of Issue: July 12, 2007

The purpose of this patent is to discover suitable drying conditions that prevent the decomposition of capsinoid compounds and increase the yield when drying capsinoid-containing chili peppers. Another purpose is to maintain the stability of capsinoids during drying of chili peppers. Chili peppers cut either before or during drying have increased surface area and ruptured outer skin. These conditions accelerate the evaporation of internal moisture, enhance drying efficiency and permit rapid drying. Frequent and uniform mixing and stirring causes moisture to evaporate evenly from the peppers, thus preventing uneven heating. The patent covers stirring at least once per hour. An air speed of 0.3 m/s or greater works well for batch drying. An air speed of 0.2 m/s or greater works well for continuous drying. An air temperature



of 65°C to 80°C is used. The hot air is directed through the bulk chili pepper material. These conditions prevent excessive heating of capsinoid and thus suitably prevented it from decomposing.

The patent covers drying Manganji peppers, Shishito peppers, Fushimi Amanaga peppers, and CH-19 Sweet peppers. It specifies that weight of peppers is reduced to less than 20% and the moisture content is reduced to less than 10% of the raw fruit. It covers the following driers: band-type, fluidized bed-type, draft-type, rotating-type, spraying-type, stirring-type, box-type, moving bed-type or drum-type. It further covers drying with a convective heat-transfer dryer, using either continuous stirring or stirring at least once an hour.

U.S. Patent No. 7,137,580 System and method for pulverizing and extracting moisture

The patent covers an apparatus for pulverizing material and extracting moisture from material. It is composed of an inlet tube, a venturi coupled to the inlet tube, an airflow generator to generate airflow with an inlet aperture, an axel coupled to the airflow generator, a balancer coupled to the axel to compensate for imbalance in the axel during rotation, and a housing at least partially encompassing the airflow generator. An outlet communicates with the input aperture, the airflow generator communicates with the venturi to direct the airflow through the venturi, and toward the input aperture.

The material introduced into the airflow passes through the venturi and is subject to pulverization and moisture extraction. A material flow rate is measured by an acoustic emission sensor, which receives the resonant frequencies generated by the material passing through the airflow generator. The material flow rate is measured to avoid overloading the system. This patent is specific to the balancing apparatuses and methods for the rotating axel.

U.S. Patent No. 7,059,550 System and method for pulverizing and extracting moisture

This patent is relevant to the same system as the previous patent, U.S. Patent 7,137,580. This patent is specific to the apparatuses that create, direct, and handle the air flow. It also covers the heat generation, pulverizing system, and material feed equipment. It contains the elaborate process of material flowing through the system. It also contains the communication between components.

U.S. Patent No. 7,040,557 System and method for pulverizing and extracting moisture

This patent is relevant to the same system as the previous patent, U.S. Patent 7,137,580. This patent is specific to the methods and apparatuses for the sensors, controllers, acoustic emission sensor, and the communication between apparatuses.

Sales Literature

Market research was an important part of the team’s research. We were interesting in determining what is available and if the client is using the best product. Listed below are the results of our market research.

Peerless Dryers

Spicy Solutions looked at this information because the client is currently using the Peerless regular dryers. Other dryers that Peerless makes are whisper dryers, quiet dryers, which are a lot like the regular dryers but they produce less noise, and semi dryers, which have been tested to dry open-top semi containers in the same way as the wagon dryers.



Figure 1. Peerless 103 Dual 3-Phase Dryer

GT Mfg. Inc Grain Dryer Specs.

These dryers are recirculating batch grain dryers that would not be feasible for our project because of the set up of the dryers. They are geared more towards small grains and would not be able to accommodate the size of the chili peppers and the rate that they need to be dried. They would not be easily incorporated into the current process based on the way they hold the grain.

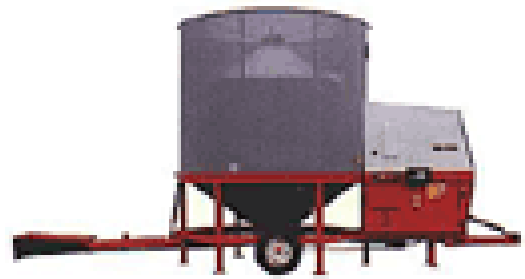


Figure 2. GT Mfg. Inc. Grain Dryer

Peanut Dryers-Diaka Model DDG 8000

This dryer is typically used for drying peanuts and seeds. The dryer removes the humidity out of the air and uses a heat pump cycle to generate drying heat. It is most efficient on summer days, making it less feasible for our project since most drying occurs in the middle of the winter. To supplement the heat pump and increasing the temperature, it has a LPG back-up burner attached that can be used during the winter months. These dryers are not a feasible for this project because they produce half of the volumetric flow rate and horsepower.



DAIKA Model DDG 8000

Figure 3. DAIKA Model DDG 8000

Blueline Crop Dryers

These dryers are most often used to dry peanuts and they are built to fit most standard peanut wagons. All Blueline Dryers can be used with LP vapor or natural gas. They offer several different models of dryers, much like the dryers offered by Peerless. The



Figure 4. Blueline Peanut Dryer Model 2712

specifications on these dryers seem to be a lot like those of the Peerless dryers so it may not be feasible for the client to replace all of the current dryers with ones that will not provide much benefit.

Research Articles

Spicy Solutions was interested in determining other methods of drying agricultural products that might be able to be applied to our problem. Below is a summary of several articles that were found, and if they are applicable to our project or not.

The dissertation, *Modeling of Deep Bed Hop Drying by Dr. Marvin Stone*, presented the team with the idea of modifying the bed depth and also modifying the air temperature and flow. This dissertation concluded that:

1. “High inlet air temperatures promote high fuel efficiency
2. Deep drying beds promote high fuel efficiency
3. Layer drying promotes fuel efficiency through deeper beds
4. Recirculation of dryer exhaust can result in fuel savings with little increase in drying time
5. Modulation of airflow and inlet air temperature can decrease drying time and fuel consumption. If temperatures and airflow are not properly managed, loss in quality may result.” (Stone, 1982)

The article *Medium Scale Solar Crop Dryers for Agricultural Products* discussed two different drying systems that were used to dry onions and bales of hay using solar air heaters. The first dryer discussed uses a corrugated galvanized steel roof and a fan that can supply 5.6 m³/s and a pressure drop of 747 Pa (Headly). For this dryer, the air is sucked into the ceiling space and ducted to a fan that blows into the plenum chamber with a perforated roof at floor

level. The bags of onions are placed on top of the plenum so the heated air does not bypass the product. This dryer doesn't have an auxiliary heating system since the farmer didn't think it was necessary (Headly). The second dryer uses a glazed 40 m² solar collector connected to a fan. The

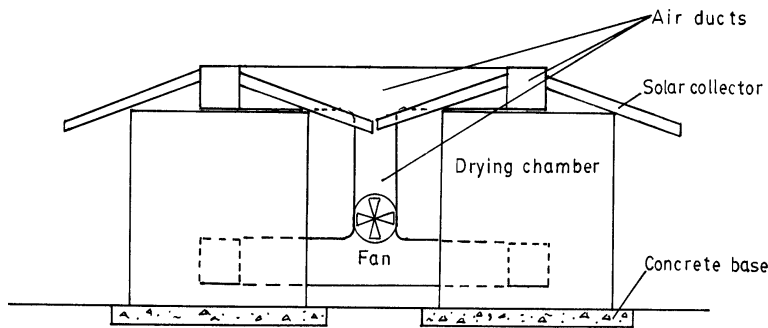


Figure 5. Dryer Set Up

drying chamber consists of two shipping containers that have been modified to improve the heat retention capabilities. The fan sucks air through the solar collector and then into the containers with the onions or hay bales. These drying options will not

work for this project most likely because the air used will not be warm enough to dry the peppers to the desired moisture content without a heater attached to the process.

The article *Dehydration of Food Crops Using a Solar Dryer with Convective Heat Flow* discussed the possible design based on the principles of convective heat flow and using it to dry food crops. By using a solar collector an ambient air of 32°C and relative humidity of 80% could be heated to 45°C at 40% relative humidity (Ayensu 1997). The crops were able to reach moisture content of <14%. The article also discusses the factor of free water in the product compared to the bound water. The use of solar energy is not applicable to this project given the season when the drying takes place.

The article *Design and Performance of an Air Collector for Industrial Crop Dehydration* reviews a test of the operation of unglazed and single-glazed solar collectors used to heat air. The collectors were tested in a range of sizes and lengths so that the pressure drops and heat transfer rates would vary (Niles 1978). Although this article is geared to industrial size crop drying

operations, it introduced the possibility of solar panels to reduce some of the cost of natural gas that the client is currently facing. Once again, the use of solar energy would not be cost effective for this project.

The paper *Curing Peanuts Using Continuous Flow Dryers* explained the results from a comparison of a single-pass continuous flow dryer, a recalculating batch dryer and a wagon drying process (Butts 2001). The study monitored drying time and quality of the peanuts after being dried. The results can be applied to the drying of peppers. The paper concluded that “using the continuous flow dryers were dried at a much faster rate than conventionally-cured peanuts” (Butts 2001). This information is applicable to this project since peppers are dried in a similar way to peanuts.

The presentation titled *Effects of Drying Procedure, Cultivar, and Harvest Number on Capsaicin Levels in Dried Jalapeno Peppers* discusses a study on how to harvest and process pepper to maintain the maximum amount of capsaicin (Pordesimo 2001). The study focused on the effects of cultivation, harvesting time and drying. The study concluded that a change in drying temperature “did not affect the concentration of total capsinoids in dried jalapeno peppers” (Pordesimo 2001). The information from this study can be easily applied to our study because it focused on non-food use peppers.

The article *Modelling of Thin-Layer Drying Kinetics of Red Chillies* investigates which temperature works best for drying peppers in a thin-layer dryer. The temperature range that was tested was 50-65°C (Kaleemullah 2006). The study took into consideration, capsaicin content, color, and drying time. The results showed that the optimal drying temperature was 55°C. This article is useful to the project if the final solution implements a thin layer drying method.

The experiment titled *Drying of Red Pepper (Capsicum Annuum): Water Desorption and Quality* dried red peppers at different air-drying temperatures. The results of the experiment show that the air drying temperature influenced the final quality of the dried red pepper (Simal 2005). It was also found an optimum range of drying for peppers to be within 50°C and 70°C (Simal 2005). The information from this experiment will be helpful when the team begins looking at desired temperature ranges for the solution.

The Web site titled *Drying Chili Peppers* was helpful to the team by describing several traditional small scale methods for drying chilies. The team did notice that typically these methods resulted in a moisture content in the chili from 8% to 12%, which is not low enough for the desired process (Sanut). Even though the Web site mentioned that the methods could be adapted to large scale processes, it does not reduce the moisture content enough to be applicable to this project.

Design Specifications

- Reduce fuel consumption of drying process
- Decrease dependence on manual labor
- Meet current production rates
- Simple operation

Design Concepts

Spicy Solutions is presenting S&S Farms with five design concepts. These concepts are discussed in more details below. The five concepts do not result in the same process efficiency, and the five concepts vary greatly in cost.

1. Peerless Dryer Modification

a. Modified Burner



- b. Modified Bed Depth
- 2. Modified Air Flow and Temperature
- 3. Air-to-Air Heat Exchanger
- 4. Continuous Flow Dryer
- 5. Recirculation
 - a. To Dryer
 - b. To Bin

Concept #1 Peerless Dryer Modification

Spicy Solutions' first concept does not change the mechanics of the current drying process. This concept allows the majority of the equipment currently used to be modified and will continue to be used in the drying process.

Modified Burner

The current burner used in the Peerless 103 dryer consists of a steel pipe with a hole drilled in the end of the pipe cap to act as an orifice. *Spicy Solutions* wants to compare efficiencies of the current burner to the Maxon's NP-LE Airflo burner by speaking with a burner companies and fuel efficiency tests. The Maxon burner has the same Btu/hr rating as the Peerless burner, but the Maxon is a line burner where the Peerless burner is a self-cleaning star burner. Figure 6 is a picture of the Maxon NP-LE burner.



Figure 6. Maxon NP-LE Airflo Burner.

Modified Bed Depth

Peerless dryers and bins were designed to dry peanuts. The peanuts were loaded until the bin was 75% full. Currently the peanut bins are filled to the top. Increasing the drying bed depth increases the thermal efficiency of drying by using all of the heated air moisture removal capacity. The increase in bed depth also increases the static pressure of the airflow. As the static pressure increases, the fans efficiency could decrease. This might result in needing a decreased bed depth to have a more efficient process. *Spicy Solutions* wants to determine the most efficient drying depth for the current Peerless fans.

Concept #2 Modified Air Flow and Temperature

Dr. Marvin L. Stone's research on decreasing the fuel consumption associated with the drying of hops for Washington State University provided *Spicy Solutions* with an alternative idea where air flow and temperature are decreased throughout the drying process. By decreasing the temperature and airflow, fuel is not wasted on heating air that is exhausted out of the top of the bed before it has reached a high relative humidity.

Humidity Sensor

A humidity sensor would be used to measure the relative humidity of the air after it has passed through the peppers. Once the humidity of the exiting air has reached a certain percentage, the temperature and airflow rate of the air going through the peppers would be altered to maximize drying capabilities of the air.

Burner and Fan Controller

A burner and fan controller would be used to adjust the fan speed and burner temperature, as necessary, through the drying process. Such a controller would eliminate

the need for a human operator, thus reducing timing delays and increasing efficiency of the drying system.

Concept #3 Air-to-Air Heat Exchanger

An air-to-air heat exchanger would use the air exiting the top of the wagon to warm the colder dry air entering the dryer. This method would allow the cold dry intake air to be warmed by the high humidity heated air before it ever reaches the dryers burner. To gain the most efficiency, the building must be enclosed, so the exhaust air is forced around the intake tubes and not blown directly into the environment by the wind.

The air-to-air heat exchanger can be placed in three locations. The first location allows the intake tube to hang from the rafters of the building. This allows the bin to move in and out without moving the heat exchanger. The second location is placing the heat exchanger on top of the drying bed. This option requires the operator to remove each exchanger before the bin can be moved. The third location is to permanently place the exchanger in the bins and allow the duct to be connected to the bin, similar to how the dryer connects to the current bins.

Locating the heat exchanger in the building's rafters requires no modification the current dryer bins. The only ducting needed for this set-up is to the dryer's intake. Locating the heat exchanger on top of the drying bed requires flexible tubing that can be moved or lifted off the bin as easily as possible. Permanently locating the heat exchanger inside the drying bin requires additional ducting to be connected to the drying bin that is flexible and can be removed easily.

Concept #4 Continuous Flow Dryer

In the continuous flow dryer the peppers are conveyed through different temperature airstreams. Belt dryers can also provide agitation by designing multiple pass dryers. A multiple pass continuous belt drying system can use the concept of recirculation easily by allowing the

wet peppers to enter into the top of the dryer and the dry peppers to exit the bottom. The heated air can then be forced from the bottom of the dryer to the top. The hot dry air passes through the semi-dry peppers to finish the drying process. The air then passes through a bed of wet peppers because it still has the ability to remove moisture. Figure 7. illustrates this process.

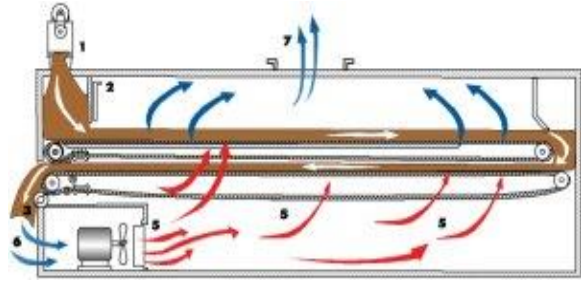


Figure 7. Belt-o-matic Dryer.

Designing a dryer that is capable of drying at the same rate as the traditional drying system is crucial. For this design, it would be ideal for the dryer's capacity to be more than what is currently being produced to accommodate the future technological advances in the growing, milling and harvesting processes.

Concept #5 Recirculation

Air can hold a certain amount of moisture before it reaches 100 percent relative humidity, a condition known as saturation. The amount of moisture air can hold depends on the temperature of the air, hotter air can hold more moisture than colder air. Thus, heating the air that is passed through the peppers allows for more moisture to be removed before the air reaches saturation. Figure 8 illustrates how the relative humidity of the exhaust air from the bins decreases as the peppers dry. As the drying process proceeds, the exhaust air from the bins has the ability to absorb more moisture. The recirculation concept involves reusing exhaust air from the bins that has yet to reach saturation. This concept is based on utilizing as much heat as possible from the air. Doing so should decrease the amount of natural gas needed to dry the peppers, thus reducing cost. Two methods were developed: recirculation to dryer and alternating bin recirculation.

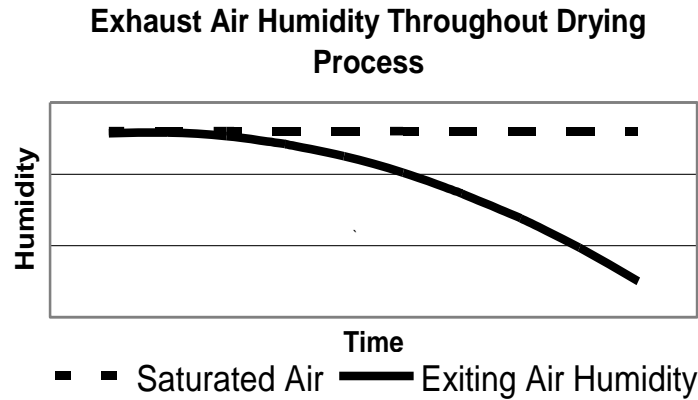
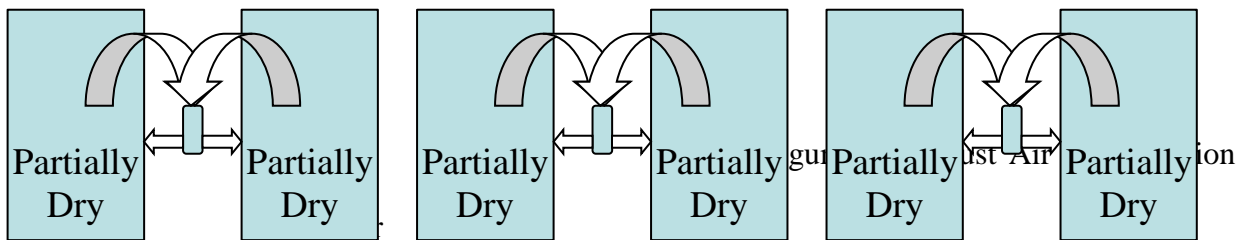


Figure 8. Air Humidity of Exhaust Air from Bin Throughout Drying Process

To Dryer

The recirculation to the dryer is done by conveying exhaust air from the bins back into the dryer. The air can be conveyed by an air duct. This material could be the same flexible material used in the dryer air ducts. A metal or hard plastic could also be used. The ducting would be suspended from the frame of the roof over the bins. The frame of the roof would need to support the weight of the ducting in order to suspend it. The fan from the dryer will create suction to move the air through the ducting. Figure 9 illustrates this method. It shows a dryer blowing air into two bins and the air exhaust from the bin blowing back into the air intake of the dryer.



Another unknown is whether recirculated air will need to be exhausted to the environment and new outside air be added to the recirculation. This depends on what point in the drying that the recirculation begins. As the air is recirculated, it is heated to a higher temperature, increasing its capacity to hold moisture. The even hotter air will have

a lower relative humidity. The relative humidity will need to be below the peppers moisture content to dry them.

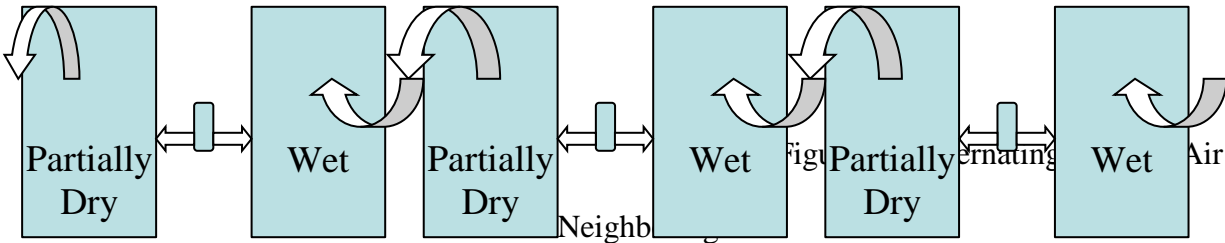
Both bins on the dryer should be started close to the same time, thus causing the peppers in the bins to reach a particular humidity near the same time. If both bins reach the same relative humidity at the same time, the recirculation will be more efficient. If the relative humidity of the exhaust air of the bins is different, one bin would continue to dry past the recirculation start point until the second bin reaches the recirculation start point. In this case, heated air that could be recirculated is lost to the environment.

It could be possible to start the recirculation of the bins independent of each other. The method of handling the airflow would become more difficult while only one of the two bins is being recirculated. It would be desirable for half of the airflow into the dryer to come from the exhaust of the recirculated bin and half to come from outside air. Without even airflow into the dryer from these two areas, the airflow would likely slow significantly in the bin where recirculation has started. This condition would likely accelerate drying in the lagging bin, which may be a benefit. However, it causes an unknown in the recirculated bin and may lead to condensation in this bin. The condensation could drip onto the peppers and increase their moisture content.

To Bin

Another method of recirculating air consists of alternating the direction of airflow between neighboring bins. The exhaust air of a partially dry bin would be added to the airflow entering the neighboring wet bin. When bins are loaded with wet peppers, they are placed at ever other bin location to create an alternating pattern of partially dry and wet bins. Figure 10 illustrates the layout of the bins and the direction of air flow. Once

the bin that was partially dry reaches the desired moisture content, it will be removed and a bin full of wet peppers will replace it. At this point, the airflow will need to be reversed, as the formerly wet bin is now partially dry.



Reversing the airflow can be accomplished by reversing the ducting. This would be easiest if the ducting were suspended from the roof frame. The ducting could be on a rotating boom, allowing it to be swung from one bin to the neighboring bin. A fan will need to be added to force the air from the top of the partially dry bin to the bottom of the wet bin. The fan can be placed between the two bins involved in the recirculation. A frame could be used to hold the fan in place, likely four to six feet above the ground. More ducting will carry air from the fan to the neighboring wet bin. This should be a reversible piece that can alternate between the two bins.

This method will cause more of the air to reach saturation. However, whenever one bin is nearly dry, the other bin receiving its exhaust air will be partially dry. Although the air leaving the nearly dry bin will aid in drying the partially dry bin, it will not reach saturation.

Cost Analysis

Peerless Dryer Modification Cost Summary

The Peerless Dryer Modification uses the majority of current drying components and current drying bins. This concept would result in increased burner and drying efficiency, resulting in a decrease of fuel consumption. A new burner costs \$800 per burner and \$200 per drying bin to increase bed depth.

Modified Air Flow Cost Summary

The MAT system, when implemented into the drying of hops, resulted in a twenty percent savings of fuel. A new burner costs \$800, the burner and fan controllers costs \$6,000 and the humidity sensor costs \$200.

Air-to-Air Heat Exchanger Cost Summary

The estimated cost associated with the air-to-air heat exchanger is dependent on the location of the heat exchanger. The different locations require a considerable difference in exchanger tube length. The concept requires the already built barns to be enclosed this would cost \$5,000. *Spicy Solutions* estimated the cost of exchanger tubes would be \$5,000.

Continuous Flow Dryer Cost Summary

The continuous flow dryer is the most expensive concept, because of the capital investment. A new custom built continuous flow dryer from Belt-o-matic dryers cost \$500,000 to \$750,000. This dryer is designed to be used in the final drying process of packaged food production. This quality of food grade drying is not required for our pepper drying, but it does have the capacity to dry to the reduced moisture of the process.

Recirculation to Dryer Cost Summary



Air ducts are estimated at \$225 per dryer. Humidity sensors are estimated to cost \$200, for an equivalent \$400 per dryer. All components of this method are estimated to cost \$625 per dryer, for a total cost of \$13,750.

Recirculation to Bin Cost Summary

Additional fans are estimated to cost \$325 per dryer, and the air ducts are estimated at \$225. This method is estimated to cost about \$550 per dryer, for a total of \$12,100 for all 22 dryers.

Table 1 contains a summary of estimated costs for each concept.

Table 1. Cost Summary of Design Concepts

Concept	Cost
Peerless Dryer Modification	\$1,000/dryer
Modified Airflow and Temperature	\$7,000/dryer
Air-To-Air Heat Exchanger	\$450/dryer
Continuous Flow Dryer	\$500,000
Recirculation to Dryer	\$625/dryer
Alternating Bin Recirculation	\$550/dryer

Next Semester

Spicy Solutions has outlined several tasks that will be completed next semester. Some of these tasks are explained in further detail below. A detailed Gantt chart is located in Appendix B.

Burner Efficiency Determination

Spicy Solutions has decided to determine the efficiency of the current burners. The results of this test will allow us to calculate potential cost savings for buying new burners. The following will be measured in this test: temperature and humidity of ambient air, air entering the bin, and air exiting the bin; pressure at the inlet of the dryer and entrance of the bin; flow rate of



gas entering burner. The temperature and humidity data will be recorded throughout the entire drying period of a bin of peppers. The other data should be consistent and does not need to be taken constantly.

Continue Component Cost Search

Spicy Solutions plans to continue searching for more cost effective components of the design concepts to reduce the cost to the client. As designs become more specific, the required components can be better selected from a range of possibilities. Our cost can then change from a rough estimate to a good estimate.

Choose a Design Concept

Spicy Solutions will select a final design concept using client feedback, results from tests, and costs savings. The potential cost savings can be calculated after we perform our planned test.



Works Cited

- Ayensu, Akwasi. 1997. Dehydration of food crops using a solar dryer with convective heat flow. *Solar Energy*. 59, 121-126.
- Butts, C.L., & Sanders, T.H.. 2001. Curing Peanuts Using Continuous Flow Dryers.
- Daika. "Peanut Dryer." *Daika*. Available from http://www.advancedryer.com/peanut_dryers.htm. Internet; accessed 11 October 2007.
- Graham, W., L. New, and W. A. Case. 2006. System and method for pulverizing and extracting moisture. U.S. Patent No. 7,137,580
- Graham, W., L. New, and W. A. Case. 2006. System and method for pulverizing and extracting moisture. U.S. Patent No. 7,059,550
- Graham, W., L. New, and W. A. Case. 2006. System and method for pulverizing and extracting moisture. U.S. Patent No. 7,040,557
- GT Mfg., Inc. "Grain Dryers." Available from http://www.gtmfg.com/grain_dryers.html. Internet; accessed 11 October 2007.
- Headly, Oliver. "Medium Scale Solar Crop Dryers for Agricultural Products." *Kenes*. Available from <http://www.kenes.com/Ises.Abstracts/Htm/0053.htm>. Internet; accessed 11 October 2007.
- Kaleemullah, S., & Kailappan, R.. 2006. Modelling of Thin-layer drying kinetics of red chillies. *Journal of Food Engineering*. 76, 531-537.
- Mori, H., T. Hirano, H. Kuhara, A. Okada, S. Yamahara. 2007. Capsinoid-containing dried chili pepper product and method of drying the same. U.S. Patent Application No. 20,070,160,729

- Niles, P.W., E.J. Carnegie, J.G. Pohl, & J.M. Cherne.. 1978. Design and performance of an air collector for industrial crop dehydration. *Solar Energy*, 20, 19-23.
- Peerless. "Peerless Dryers." *Peerless*. Available from <http://www.peerlessmfg.cc/dryers1.htm>. Internet; accessed 11 October 2007.
- Pordesimo, L.O., Li, H., Reddick, B.B., & Habera, L.F.. 2001. Effects of Drying Procedure, Cultivar, and Harvest Number on Capsaicin Levels in Dried Jalapeno Peppers.
- Sanut, John. "Drying Chile Peppers." Available from <http://www.g6csy.net/chile/drying.html>. Internet; accessed 12 October 2007.
- Simal, S., Garau, C., Femenia, A., & Rossello, C.. 2005. Drying of Red Pepper (*Capsicum Annuum*):. *International Journal of Food Engineering*, 1, 1-14.
- SMF Associates. "Blueline Crop Dryers." *Blueline Dryers*. Available from <http://www.bluelinedryers.com/blueline-dryers.htm>. Internet; accessed 11 October 2007.
- Stone, Marvin L., 1982. Modeling of deep bed hop drying. PhD diss. Pullman, Wash.: Washington State University, Program of Engineering Science.

Appendix A

Patents Search

Appendix B

Gantt Chart



Design of an Efficient Drying System

Kyle Dollins

Becca Hoey

Michael Matousek

BAE 4012

Problem Statement

Develop a time and cost effective drying method to reduce the overhead associated with the increasing price of natural gas by improving the existing or proposing an alternative drying process.



S & S Farms

- Located in Hinton, Oklahoma
- 1200 acres of super hot chili peppers
- Used in the pharmaceutical industry
- Hand transplanted
- Mechanically harvested



Problem Introduction

- Minimize fuel consumption
- Reduce moisture content, must be 5%
- Initial moisture content ranges between 30-60%
- Process 1.7 million pounds
- Averages 60,000 pounds per day



Current Process

- Peanut wagons
- Peerless 103 dual 3-phase dryers
- Open sided barns open to the environment
- Natural gas burners
- Peppers remain in field as long as possible
- Milled into a powder
- Bagged and shipped



Design Specifications

- Reduce fuel consumption of drying process
- Decrease dependence on manual labor
- Meet current production rates
- Simple operation



Market Research

- Daika Peanut Dryer Model DDG 8000
- Blueline Peanut Dryers Model 2712



DAIKA Model DDG 8000

http://www.advancedryer.com/peanut_dryers.htm



<http://www.bluelinedryers.com/m2712.htm>



Patents Search

- U.S. Patent No. 7,059,550 System and method for pulverizing and extracting moisture
 - Venturi generates turbulent airflow
 - Materials are turned into powder
 - Cyclone separates powder from air
 - Multiple stages increase drying
 - Adding heat increases drying



Literature Review

- Several articles using solar energy
 - Impractical because drying occurs during the winter
 - Solar panels used to reduce the amount of natural gas used



Concept #1

Peerless Dryer Modifications

- Uses majority of current equipment
 - Modify Burner
 - Modify Bed Depth

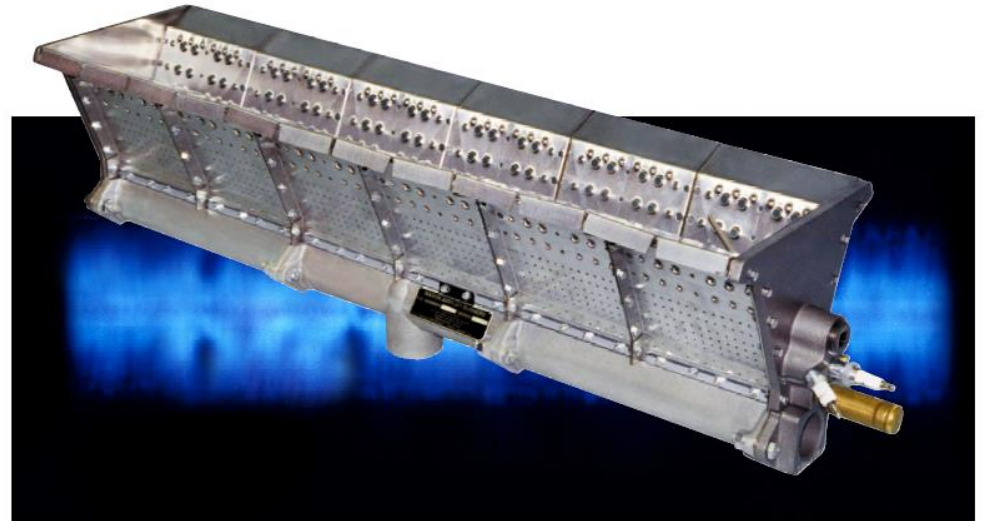


<http://www.progress-energy.com/custservice/flabusiness/efficiency/CA/library/MISC002.asp>



Modify Burner

- Increase air temperature
- Increase burner efficiency
- Tests to Perform:
 - Orifice size comparison
 - Heating efficiency



<http://www.maxoncorp.com/Files/pdf/B-lb-nple.pdf>

Modify Drying Bed Depth

- Originally designed to be $\frac{3}{4}$ full of peanuts
- Currently bins are full of peppers
- Increasing bed depth increases fuel efficiency
- Deeper beds also increase static pressure
- Static pressure affects fans efficiency
- Tests to perform
 - Static pressure measurements
 - Fan performance curve



Concept #1 Summary

- Main Advantages
 - Current Drying Bins
 - Decreased fuel consumption
- Associated Cost
 - \$800 - New Burner
 - \$200 - Side Board



Concept # 2

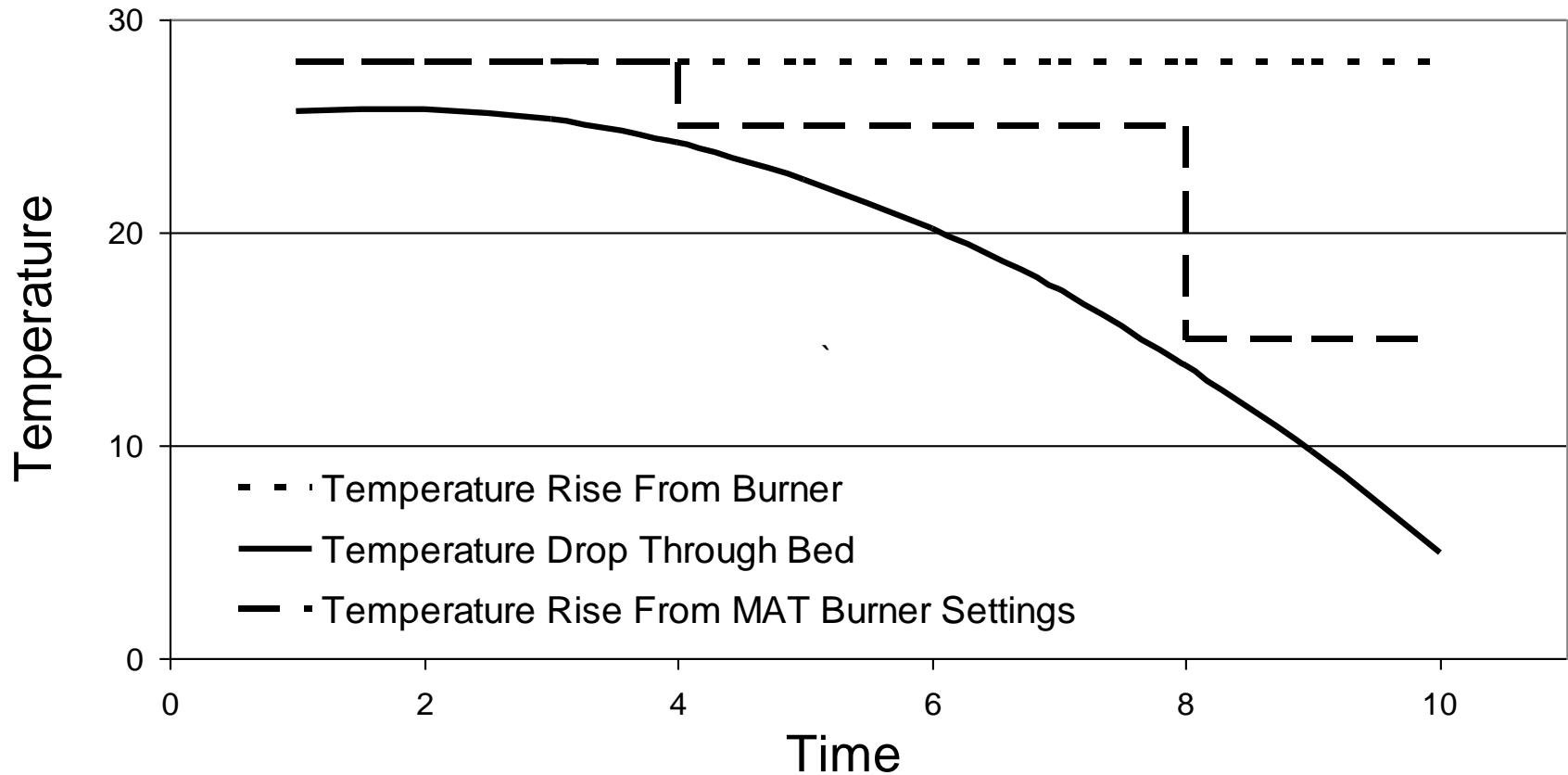
Modulation of Airflow and Temperature

- As drying process progresses
 - Decrease air temperature
 - Decrease airflow
- Components
 - Temperature and humidity sensor
 - High turndown ratio burner
 - Fan speed and burner controller



Modulation of Airflow and Temperature

General Explanation of Modulation of Airflow Temperature



Concept # 2 Summary

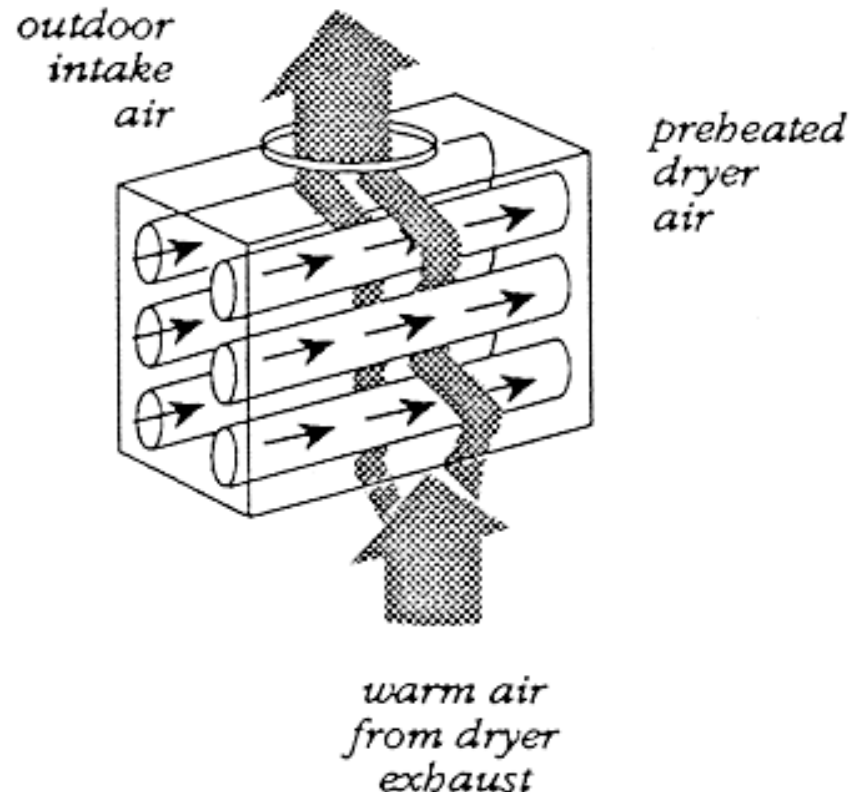
- Main Advantage
 - Decrease in fuel consumption
- Associated cost
 - \$800 – New burner
 - \$6,000 – Burner controller
 - \$200 – Sensors



Concept #3

Air-To-Air Heat Exchanger

- Pre-heat dryer's intake air supply
- Extract heat from dryer's exhaust air
- Intake tubes above drying bins
- Enclosed building



Concept # 3 Summary

- Variation in exchanger placement
 - Above bins
 - Top of peppers
 - In peppers
- Associated Cost
 - \$5,000 - Enclosing building
 - \$5,000 - Air ducts



Concept #4

Continuous Flow Dryer

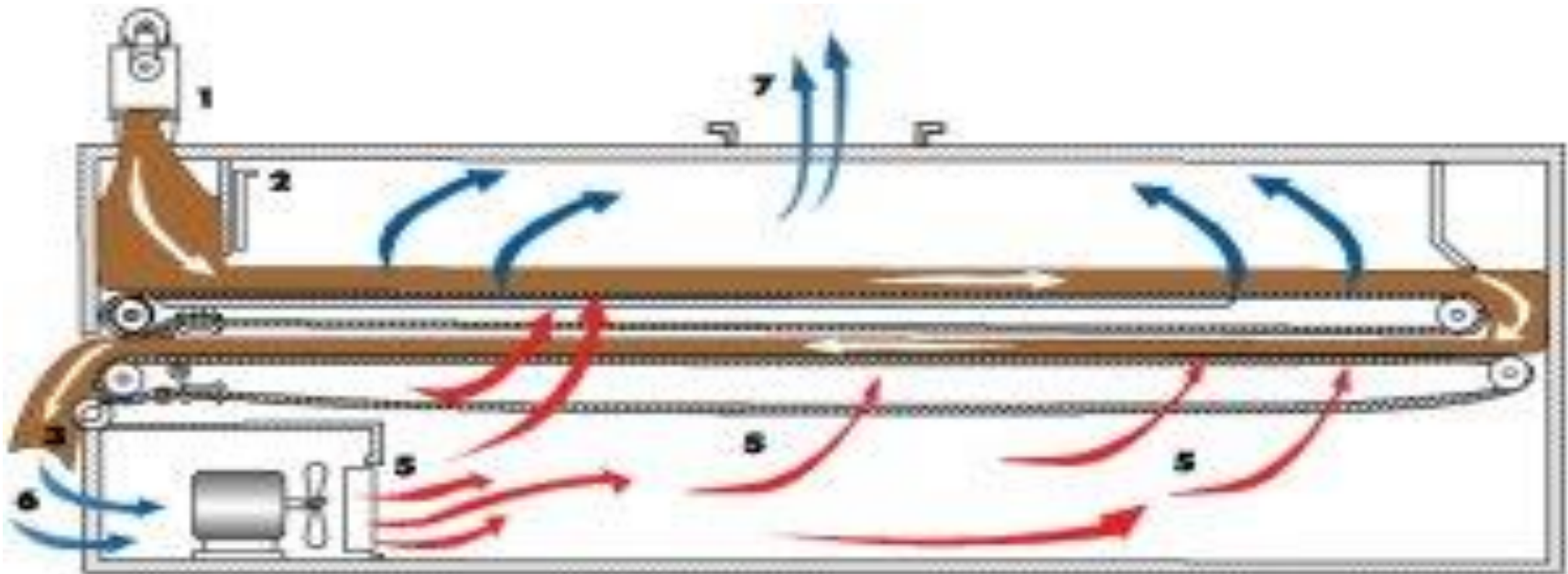
- Decrease the handling of peppers
- More complex
- High capital cost



<http://www.belt-o-matic.com/Documents/Belt-o-matic.pdf>



Continuous Flow Dryer



<http://www.belt-o-matic.com/singlestagemultipass.htm>

Concept # 4 Summary

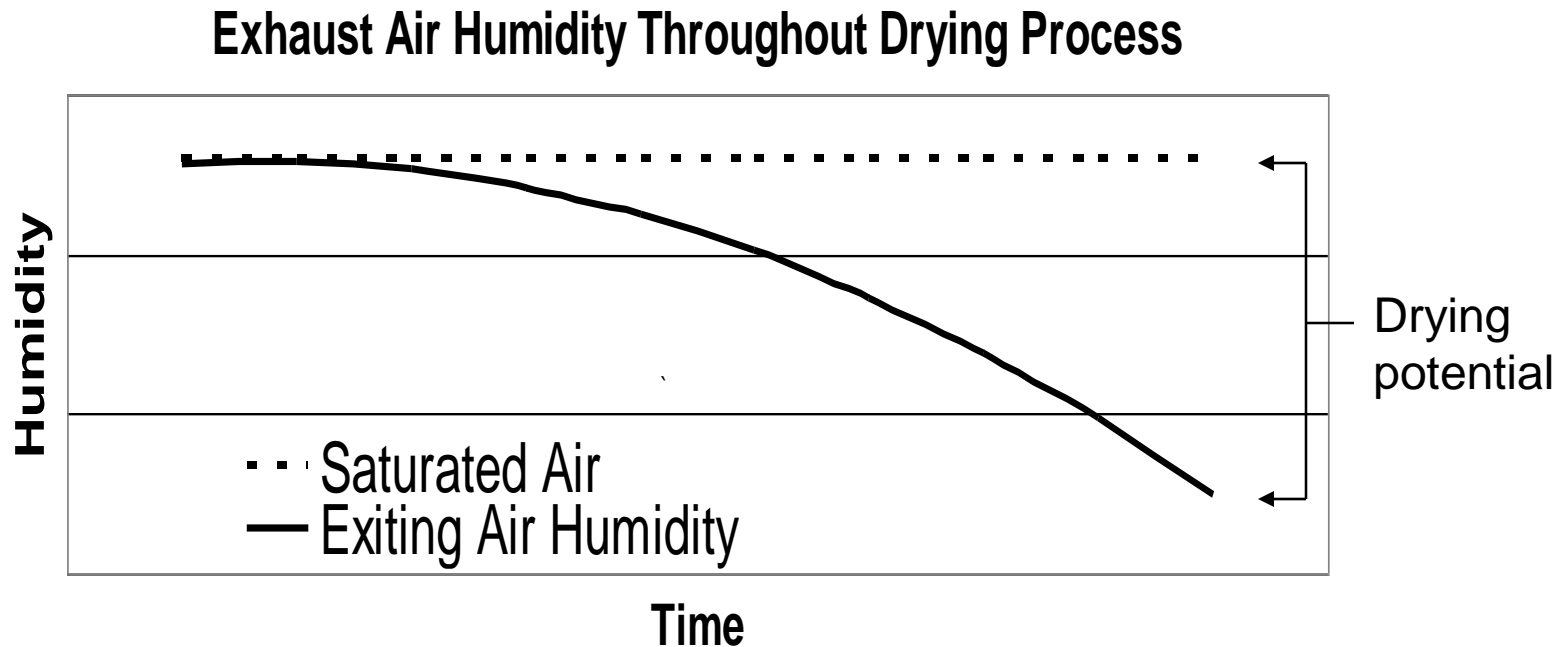
- Can be integrated into current continuous milling process
- Associated Cost
 - \$500,000 – Dryer
 - Custom built
 - Food grade
 - Purchased from vendor
- Possible cost reduction



Concept #5

Recirculation

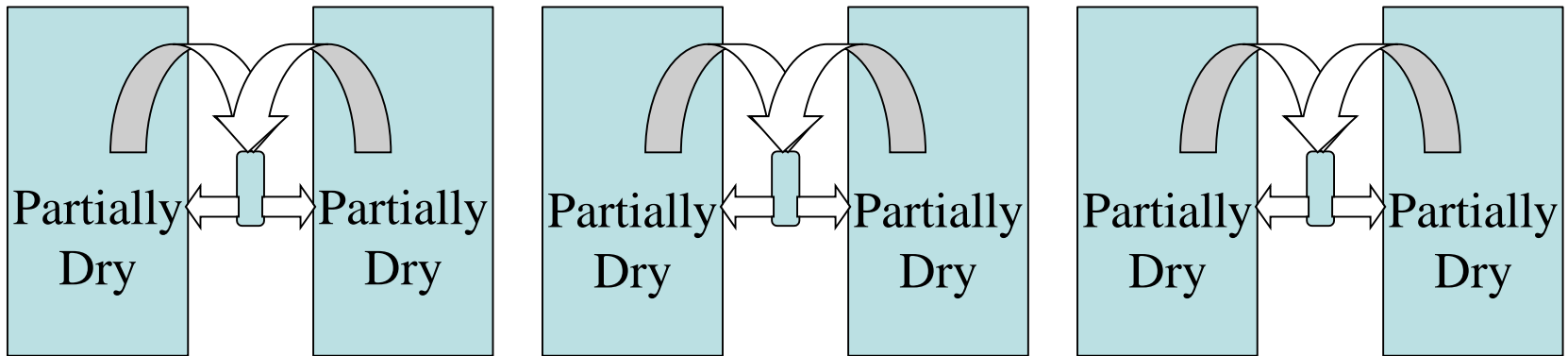
- Make use of exhaust air currently wasted



- Two recirculation concepts



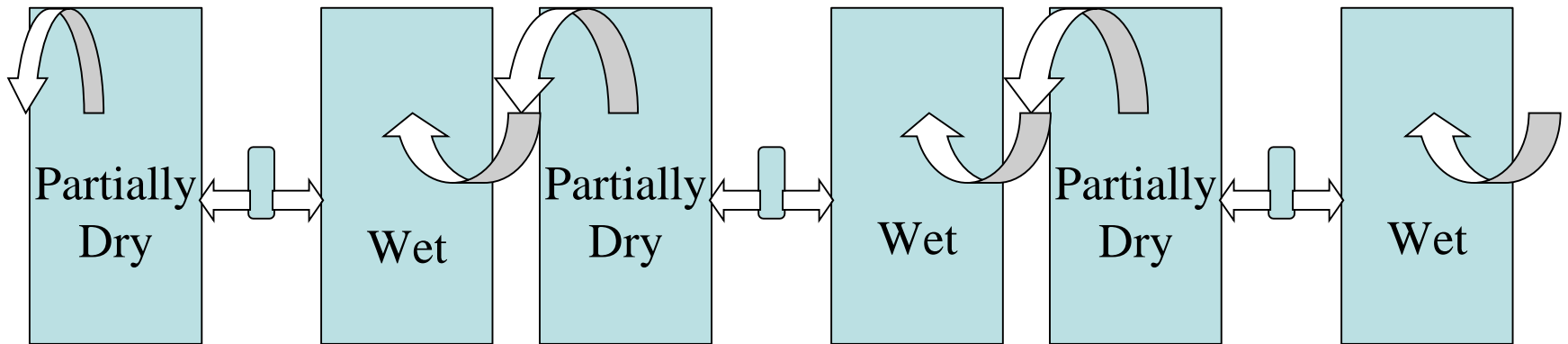
1st Recirculation Concept



- Start recirculation once peppers partially dry
- Convey air exiting bins back into the dryer
- Can achieve higher air temperatures

2nd Recirculation Concept

- Alternate wet and dry bins



- Convey air exiting partially dry bin to wet bin
- Saturate air before releasing into atmosphere
- Requires additional fan

Concept #5 Summary

- 1st Method
 - Associated cost per dryer
 - \$225 – duct work
- 2nd Method
 - Associated cost per dryer
 - \$325 – fan
 - \$225 – duct work



Rough Cost Estimates

Concept	Cost
Peerless Dryer Modification	\$1,000/dryer
Modified Airflow and Temperature	\$7,000/dryer
Air-To-Air Heat Exchanger	\$450/dryer
Continuous Flow Dryer	\$500,000
Recirculation (into dryer)	\$225/dryer
Recirculation (alternating)	\$550/dryer



Next Semester

- Continue searching for less expensive components
- Find fuel efficiency of current burners
- Use feedback to help determine direction
- Perform needed tests



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- Dr. Marvin Stone



Questions?

