Solar Thermal Specialty Crop Drying Research at the USDA – Agricultural Research Service

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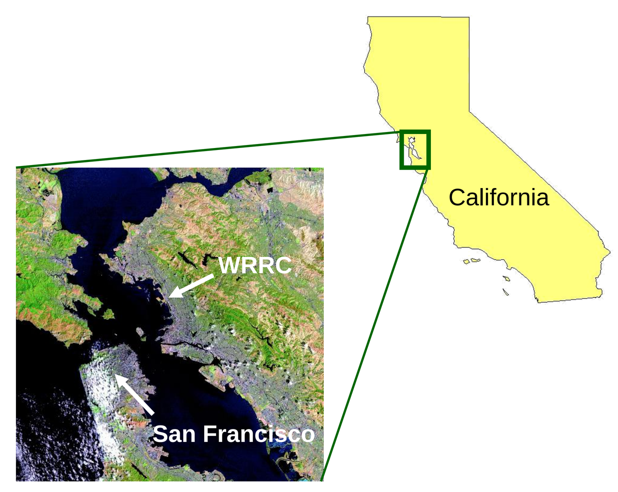
USDA-ARS

The Agricultural Research Service (ARS) is the U.S. Department of Agriculture's chief scientific research agency. Our job is finding solutions to agricultural problems that affect Americans every day, from field to table. Here are a few numbers to illustrate the scope of our organization:

- 800 research projects within 17 National Programs
- 2,100 scientists and post docs
- $1.1 billion fiscal year 2009 budget
- 100 research locations including a few overseas

http://www.ars.usda.gov/AboutUs/AboutUs.htm

Western Regional Research Center



Healthy Processed Foods Research Unit

Solar thermal processing of specialty crops is a project that is part of the Healthy Processed Foods Research Unit (HPFR) at the USDA-ARS WRRC location. The mission of HPFR is to enhance the marketability and healthfulness of agricultural commodities and processed products. Cereal grains, legumes, and fruits and vegetables are the focus of this research. Both fundamental and applied research approaches are used to solve problems and develop new value-added products which will benefit the consumer, producer, economy and environment. Important consideration is given to fundamental food properties, nutritional attributes, and consumer preferences. Research approaches are multidisciplinary.

http://www.ars.usda.gov/pwa/wrrc/pfru

Motivations

Solar dehydration ("drying") of crops is an ancient food preservation technology. Previously, research in this area was primarily performed by academics in Africa and South Asia; however, it is gaining renewed interest from U.S. food processors due to the increasing cost of energy from fossil fuels and product variability using traditional solar drying methods. These studies have three common characteristics:

- ***Time-consuming prototyping of cabinet and solar collector (air heating unit)*** Researchers physically construct a cabinet dryer and then determine the drying times of various agricultural products within that dryer. Drying experiments can only be performed during conducive times of the year.
- ***Static treatment of material*** Once the crop is placed in the dryer, it is left in the same location with no changes to processing conditions beyond natural shifts in temperature due to changing insolation.
- ***Construction materials selected for convenience*** Wood, sheet metal, and plastic sheeting are the most often-used materials due to their low cost and ubiquity.

Research Approach

The overarching goal of ARS's program in this area is to develop solar or solar-assisted cabinet dryer designs optimized for a given specialty crop* and location. We will do this by addressing the three shortfalls of the current research, as described at left. Our target customers are small- and medium-sized specialty crop processors in the American West who currently dry their crops using natural gas-fired cabinet dryers. In our experiments, we will

- ***Test dryer designs using multiphysics modeling software, then construct prototypes*** We will develop a multiphysics computer model of a simple dryer using the software package COMSOL Multiphysics. We will then validate the model against experimental runs in a physical version of this dryer, and use the model to direct design of solar collectors, modifications to the cabinet, and possible addition of an auxiliary component (e.g. fan) to create an active (forced convection) system.
- ***Employ dynamic feedback and feedforward control of dryer configuration based on real-time measurements*** We cannot control the weather; however, we can measure ambient temperature, humidity, insolation, etc. as well as the mass, temperature, etc. of the product. This information will be utilized to adjust product location within the dryer, orientation of the solar collector, fan speed, etc. to enable the most efficient use of the solar energy that is available at any given time and thereby, optimize drying conditions.
- ***Select "smart" dryer construction materials to minimize drying time and improve product quality*** Current dryer construction materials have suboptimal optical properties. Improving these properties, while keeping an eye on material costs, will shorten drying time and improve product quality. We will also consider incorporating a thermal energy storage unit in the design to enable drying outside of daylight hours. However, prior to implementation of the latter, certain parameters must be attained to ensure thermal conditions are met to utilize the heat storage capacity of phase change materials.

* Specialty crops include fruits, vegetables, nuts and other horticultural crops defined by the USDA – Agricultural Marketing Service.

Challenge 1: Multiphysics Modeling of the Food/Dryer/Environment System

Our goal is to develop a robust, 3-dimensional model of the entire drying system, including the food material, the dryer, and the environment immediately surrounding the dryer. Once validated against experimental data, this model could be used to perform virtual experiments and test out refinements in dryer design outside of the harvest season for a given specialty crop.

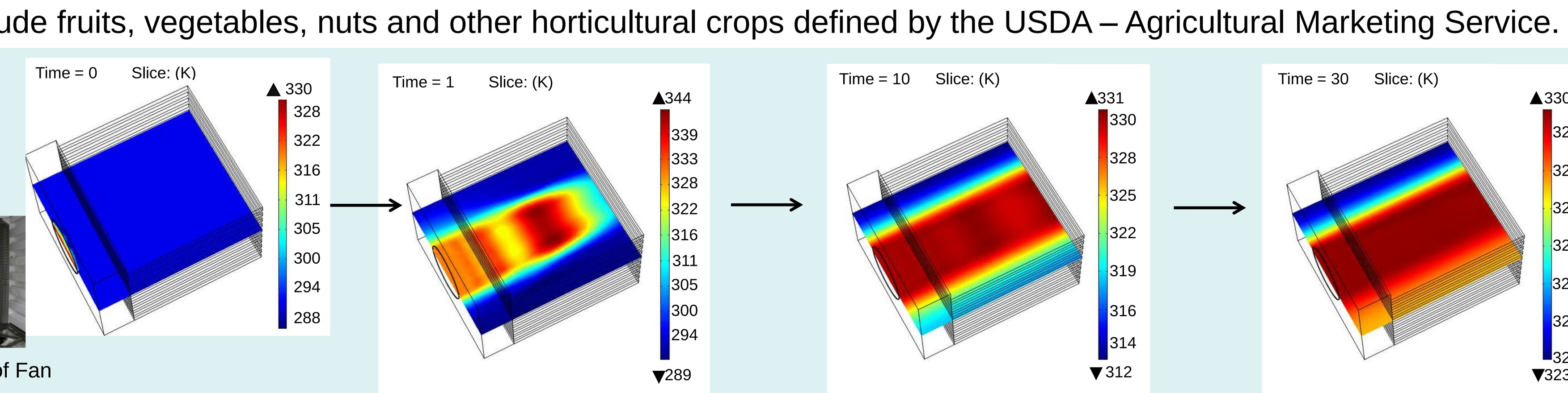
Progress To Date

- Modeled temperature in and air flow through a bench-scale convection dehydrator.
- Constructed outdoor solar drying cabinet with geometry that mirrors lab dehydrator.
- Conducted full sponge-drying experiments with lab dehydrator.
- Determined spatial variation in drying rate.
- Conducted preliminary sponge-drying experiments with solar drying cabinet.
- Measured multiple weather metrics (temperature, humidity, insolation, etc.) during drying experiments.

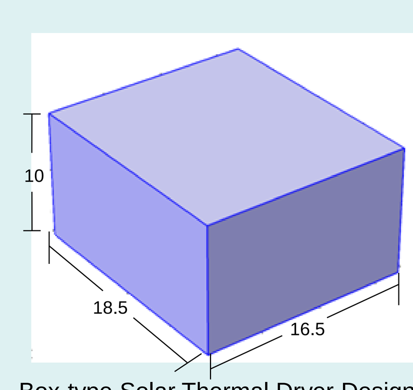
Next Steps

- Validate multiphysics model with experimental data from box-type solar cabinet using various optical materials. (Fall 2014)
- Collect additional data on sponge drying in box-type solar drying cabinet. (Fall 2014)
- Add time-varying insolation to multiphysics model. (Spring 2015)
- Model cabinet temperature in box-type cabinet dryer using location specific, time-varying insolation. (Spring 2015)

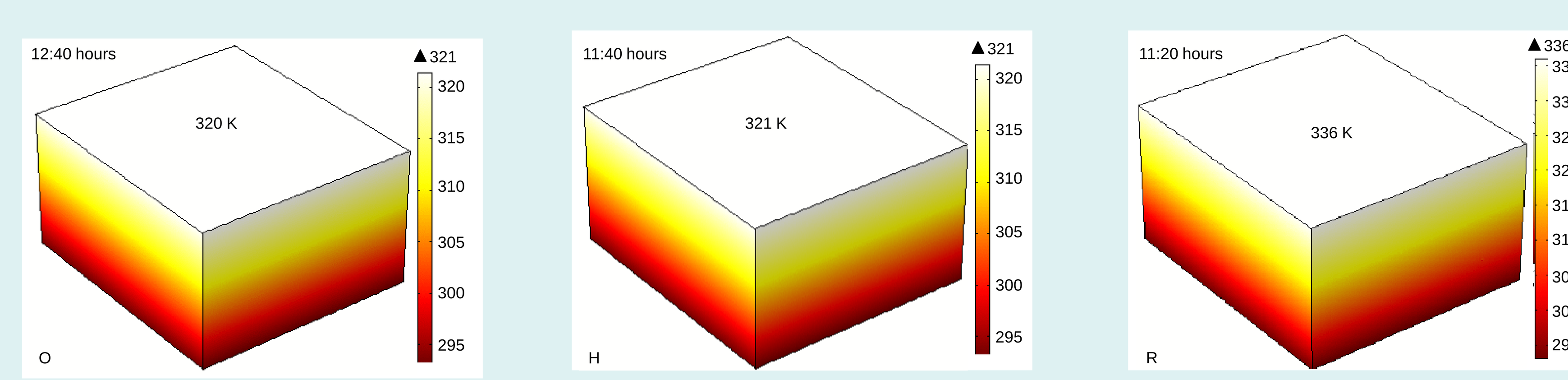
Benchtop Dehydrator and Close-up of Fan



COMSOL Model: Temperature Distribution at Center Tray at Time = 0 Seconds, 1 Second, 10 Seconds, and 30 Seconds



Box-type Solar Thermal Dryer Design
as Modeled in COMSOL
(Units are in Inches)



COMSOL Model: Temperature Distribution at Peak Temperature Time = 12:40 hours (O), 11:40 hours (H), 11:20 Hours (R)
Absorptivity and Emissivity: Original (O) – 0.2 and 0.8; Half-Half (H) – 0.5 and 0.5; Reversed (R) – 0.8 and 0.2

Challenge 2: Design a Feedback/Feedforward Dryer Control System

Solar thermal drying of food crops is, fundamentally, a food processing unit operation. Unit operations produce the best results when they are controlled by an appropriate feedback and/or feedforward algorithm. Our team aims to develop modern control systems that will enable the most efficient use of the solar energy that is available at any given time. Feedback control involves measurement of the system state (product moisture content and product temperature, for example) and adjustment of independent variables (fan speed, solar collector orientation, and so on) to bring the system state closer to a desired setpoint. Feedforward control involves measurement of external disturbances (external temperature and insolation, for example) and similar adjustment of independent variables to compensate for these disturbances.

Progress To Date

- Measured 2 years of microclimate data for the Albany, California solar dryer testing area.
- Set up temperature data logging system for interior of solar dryer cabinet.

Next Steps

- Set up humidity data logging system for interior of solar dryer cabinet. (Spring 2015)
- Determine appropriate feedback and feedforward algorithms and software for implementation. (Spring 2015)
- Configure lab dehydrator for dynamic feedback control. (Summer 2015)
- Outfit solar dryer cabinet with auxiliary fan and heater. (Summer 2015)

Challenge 3: Determine Optimal Dryer Construction Materials

Throughout the literature we find a myriad of solar dryer designs: box-type, chimney, tunnel. However, to date, very few attempts have been made to optimize the optical characteristics of solar dryer cabinet construction materials. Previous research at the USDA-ARS and elsewhere has shown that laboratory-generated light in various parts of the solar spectrum can aid in dehydration and can increase certain nutritious components of specialty crops. Unfortunately, exposure to sunlight is also known to degrade the quality of some fruit and vegetable products. Our team will test multiple solar spectrum-filtering materials for their effects on drying time and product nutritional quality.

Progress To Date

- Conducted literature survey of postharvest effects of various parts of the solar spectrum on fruit and vegetable crops.
- Screened filter materials using a portable spectrophotometer.
- Incorporated interchangeable filter materials into solar drying cabinet.
- Conducted side-by-side comparisons of fruit dried under different filtered-sunlight environments.

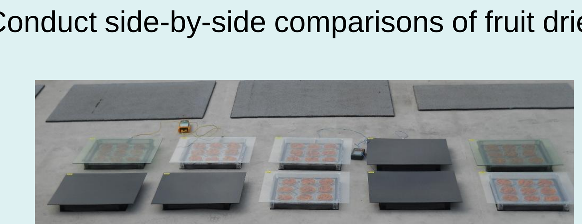
Next Steps

- Incorporate interchangeable optical materials into solar drying cabinet. (Fall 2014)
- Confirm emissivity values of selected materials. (Winter 2014)
- Conduct side-by-side comparisons of fruit dried under different solar drying conditions. (Spring 2015)

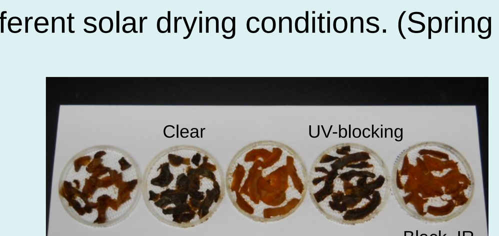
Sponge Drying Experiment in Benchtop Dehydrators

Researcher Rebecca Milczarek Removes
a Tray from the Box-Type Solar Dryer

Sponge Drying Experiment in Box-Type Solar Dryer



Single Layer Solar Drying Unit using Different Cover Materials



Dried Fruit under Different Filtered-Sunlight Environments

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Collaborations

USDA-ARS is eager to collaborate with UC Solar faculty, staff, and students on projects of mutual interest. If you are interested in learning more about USDA-ARS's solar thermal food processing program, please contact Dr. Fatima Alleyne or Dr. Rebecca Milczarek.