Solar 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:

- 1,200 research projects within 21 National Programs
- 2,100 scientists
- $1.1 billion fiscal year 2009 budget
- 100 research locations including a few in other countries

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

Western Regional Research Center

Processed Foods Research Unit

Solar thermal processing of specialty crops is a project that is part of the Processed Foods Research Unit (PFR) at the USDA-ARS WRRC location. The mission of PFR 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 to be used to solve problems and develop new value-added products which will benefit the consumer, producer, economy and environment. Fundamental food properties, nutritional attributes, and consumer preferences are important considerations. Research approaches are multidisciplinary.

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

Motivations

Solar dehydration ("drying") of crops is an ancient food preservation technology that is gaining renewed interest from U.S. food processors due to the increasing cost of energy from fossil fuels. In the recent past, research in this area has been performed primarily by academics in Africa and South Asia. These studies have three common characteristics:

- ***Time-consuming prototyping of cabinet and solar collector (air heating unit)*** Researchers physically construct a cabinet drier and then determine the drying times of various agricultural products within that drier. 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 overall 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 drier 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 a 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 and use this information to adjust product location within the dryer, orientation of the solar collector, fan speed, etc. This will enable the most efficient use of the solar energy that is available at any given time.
- ***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.

* 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.

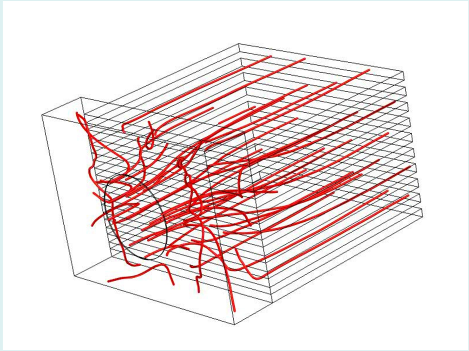
Progress To Date

- 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.

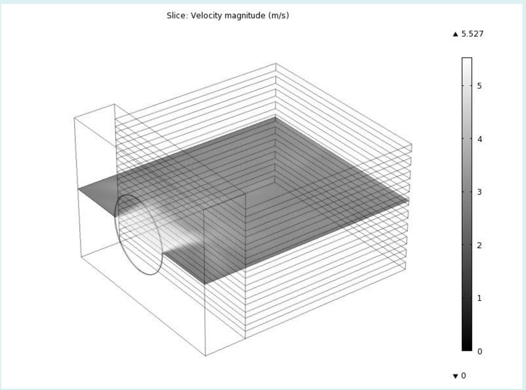
Next Steps

- Validate multiphysics model with experimental data from lab dehydrator. (Winter 2012)
- Add time-varying insolation to multiphysics model. (Spring 2012)
- Collect additional data on sponge drying in solar drying cabinet. (Summer 2012)
- Validate multiphysics model with experimental data from solar cabinet. (Fall 2012)

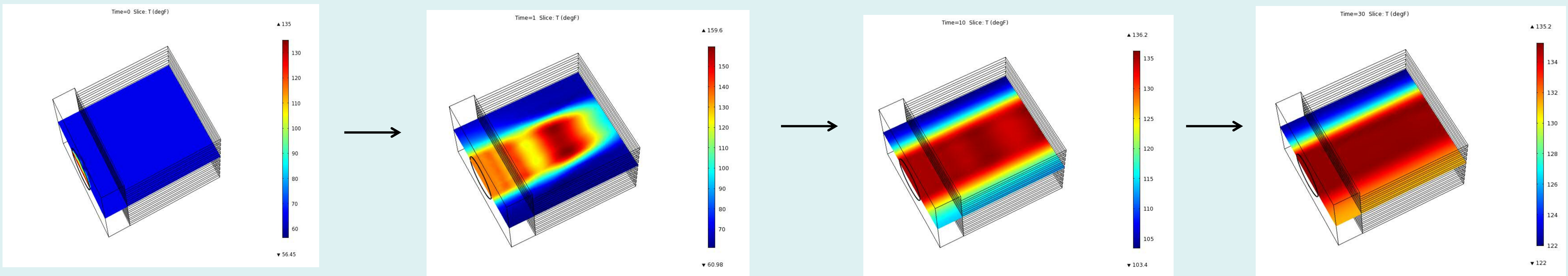
Benchtop Dehydrator and Closeup of Fan



COMSOL Model: Air Particle Streamlines Through Cabinet

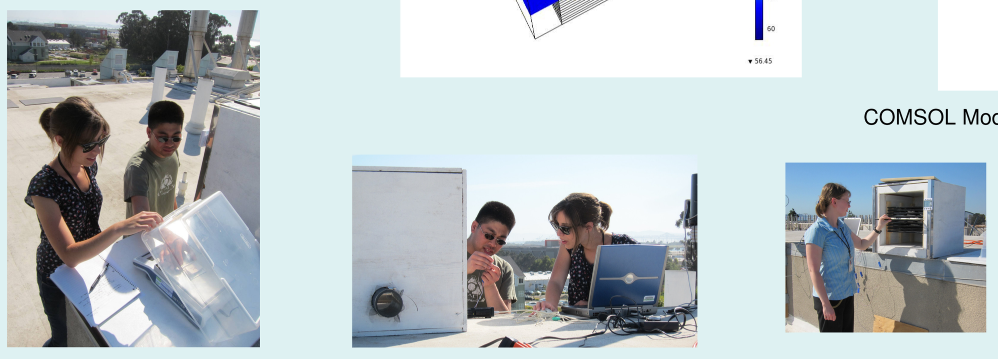


COMSOL Model: Steady-State Magnitude of Air Velocity at Center Tray



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

Sponge Drying Experiment in Benchtop Dehydrators



Technicians Laure Vallot and Matt Tom Conduct Sponge Drying Experiment with Solar Dryer Cabinet; Researcher Becky Milczarek Removes a Tray from the Solar Dryer

Challenge 2: Design a Feedback/Feedforward Dryer Control System

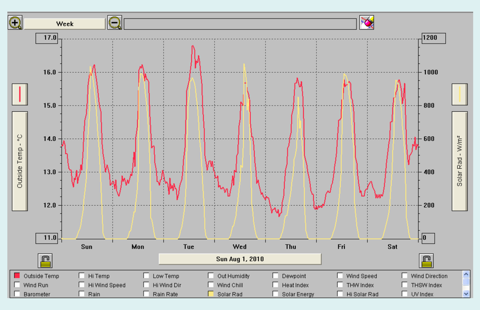
Solar thermal drying of food crops is, fundamentally, a food processing unit operation. Unit operations produce the best results when they are controlled by an appropriate feedback and/or feedforward algorithm. Our team aims to develop modern control systems that will enable the most efficient use of 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. (Winter 2012)
- Configure lab dehydrator for dynamic feedback control. Determine appropriate feedback and feedforward algorithms and software for implementation. (Spring 2012)
- Outfit solar dryer cabinet with auxiliary fan and heater. (Spring 2012)
- Configure solar dryer cabinet for dynamic feedback control. Determine appropriate feedback and feedforward algorithms and software for implementation. (Summer 2012)



Sample Data from Weather Station

Technician Matt Tom Checks Output from the Weather Station

Technician Matt Tom Checks Readings from Thermocouples Arranged Inside the Solar Cabinet Dryer

Challenge 3: Determine Optimal Dryer Construction Materials

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. However, 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.

Next Steps

- Screen filter materials using a portable spectrophotometer. (Winter 2012)
- Incorporate interchangeable filter materials into solar drying cabinet. (Spring 2012)
- Conduct side-by-side comparisons of fruit dried under different filtered-sunlight environments. (Summer 2012)

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. Rebecca Milczarek.

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