Solar Thermal: Exploring the World's Oldest (and Newest) Food Processing Technology

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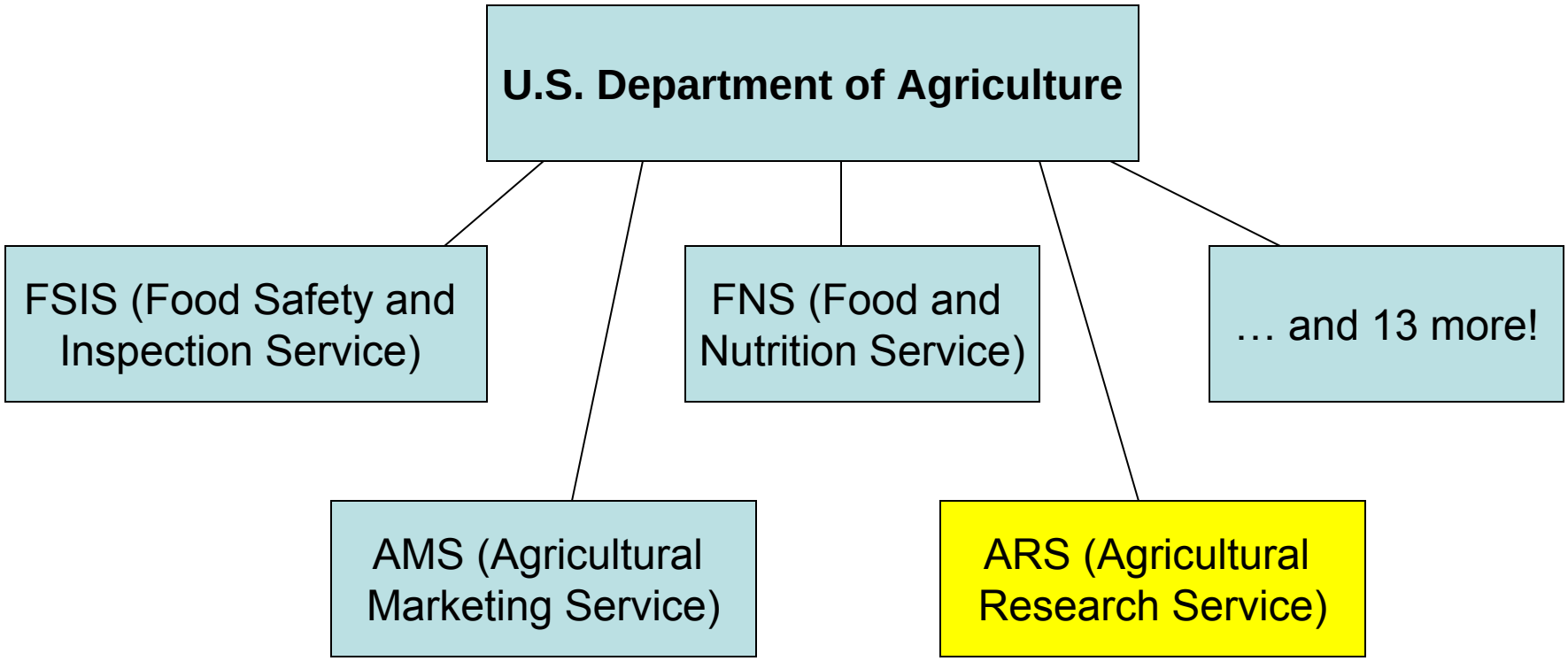

USDA – Agricultural Research Service

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.

- 1,200 research projects within 21 National Programs
- 2,100 scientists
- 6,000 other employees
- 100 research locations including a few in other countries
- $1.1 billion fiscal year 2012 budget

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Processed Foods Research Unit

New Sustainable Processing Technologies to Produce Healthy, Value-Added Foods from Specialty Crops and Their Co-Products

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

The World's Oldest* Food Processing Technology

- Middle Eastern and East Asian cultures were sun-drying foods as early as 12,000 B.C.E.[1]
- Early Bronze Age (3,300 to 2,100 B.C.E.) raisins and dried figs recently identified in an archaeobotany study of a site in modern-day Pakistan[2]

* All right – we don't know for sure, but it is certainly *one of* the oldest food processing technologies!

Figure 1 Early Bronze Age charred whole grape or raisin. x11

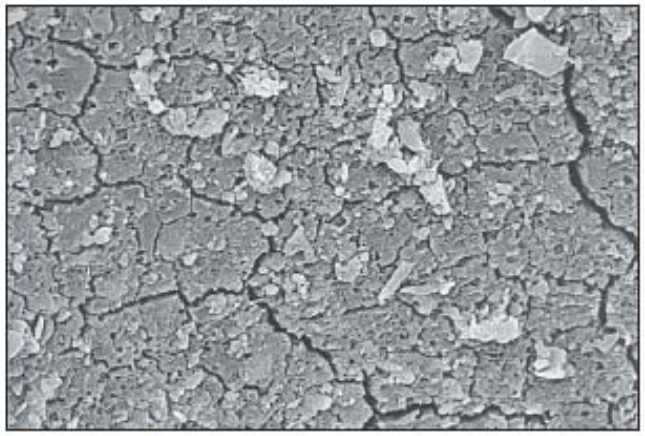


Figure 2 SEM photomicrograph of crystalline features on the grape surface. x1000

1 - "Historical Origins of Food Preservation" http://nchfp.uga.edu/publications/nchfp/factsheets/food_pres_hist.html

2 and figure - Cartwright, C.R. 2003. "Grapes or raisins? An early Bronze Age larder under the microscope" Antiquity 77(296): 345-348.

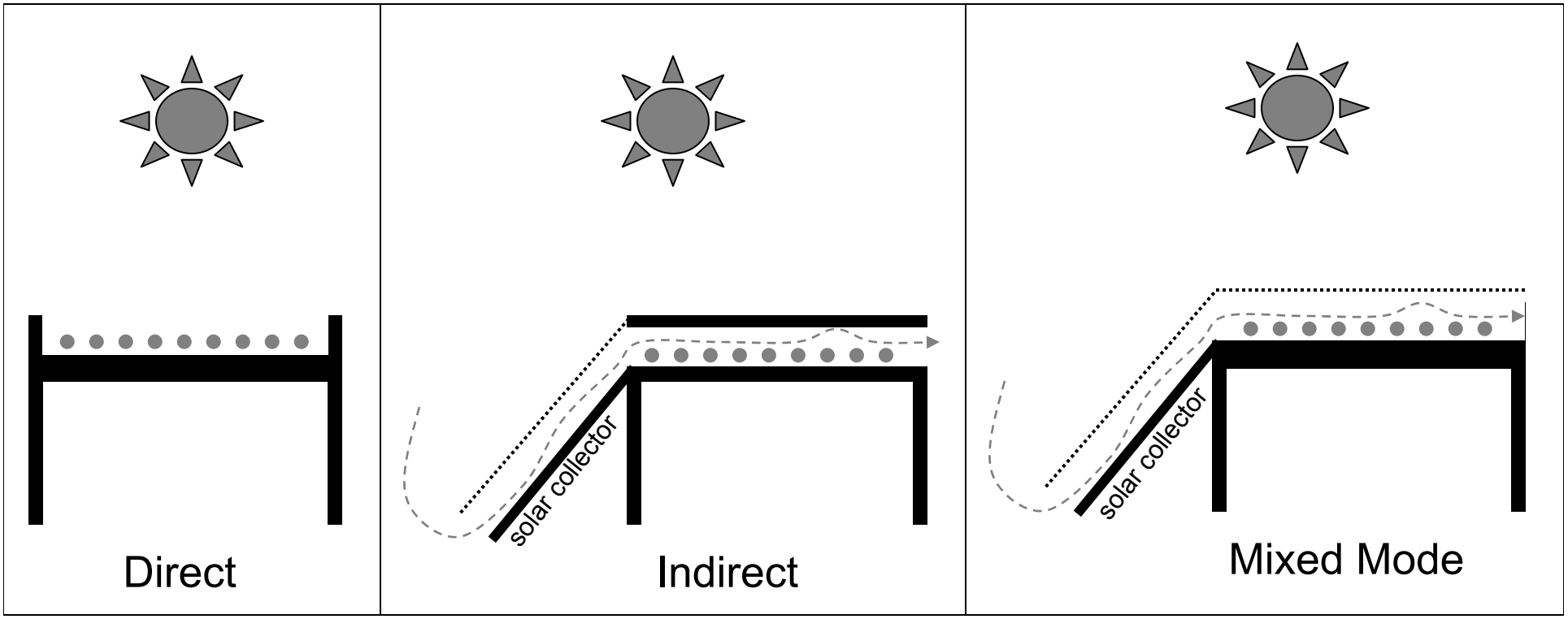
Sun Drying vs. Solar Thermal Drying

= opaque material

= transparent or translucent material

= air

= food product



Sun Dryer Design

Solar Thermal (ST) Designs

Solar Dryer Research: Active Countries 1998-2013

Direct Drying

- Bangladesh (1)
- Belgium (1)
- Canada (1)
- China (4)
- France (1)
- India (3)
- Israel (1)
- Korea (1)
- Libya (1)
- Malaysia (3)
- Mexico (1)
- New Zealand (3)
- Nigeria (7)
- Portugal (4)
- Slovenia (1)
- Spain (1)
- Thailand (3)
- Tunisia (2)
- Turkey (4)
- Uganda (2)
- United Kingdom (3)
- U.S.A. (1)
- Venezuela (1)

Numbers in parentheses are counts of journal articles with at least one author from the country. (total articles covered ≈ 100; some articles have authors from multiple countries and/or cover both direct drying and indirect/mixed mode drying)

Solar Dryer Research: Active Countries 1998-2013

Indirect/Mixed Mode Drying

- Algeria (2)
- Bangladesh (3)
- Brazil (1)
- Cambodia (1)
- Canada (2)
- China (1)
- Czech Republic (1)
- Egypt (1)
- Ethiopia (1)
- France (2)
- Germany (2)
- Ghana (1)
- Greece (1)
- India (18)
- Indonesia (1)
- Iran (2)
- Iraq (1)
- Kenya (1)
- Libya (1)
- Malaysia (2)
- Mexico (1)
- Morocco (4)
- New Zealand (1)
- Nigeria (5)
- Pakistan (1)
- Portugal (3)
- Spain (1)
- Tanzania (1)
- Thailand (6)
- Tunisia (3)
- Turkey (9)
- U.S.A. (2)
- Venezuela (1)
- Vietnam (1)

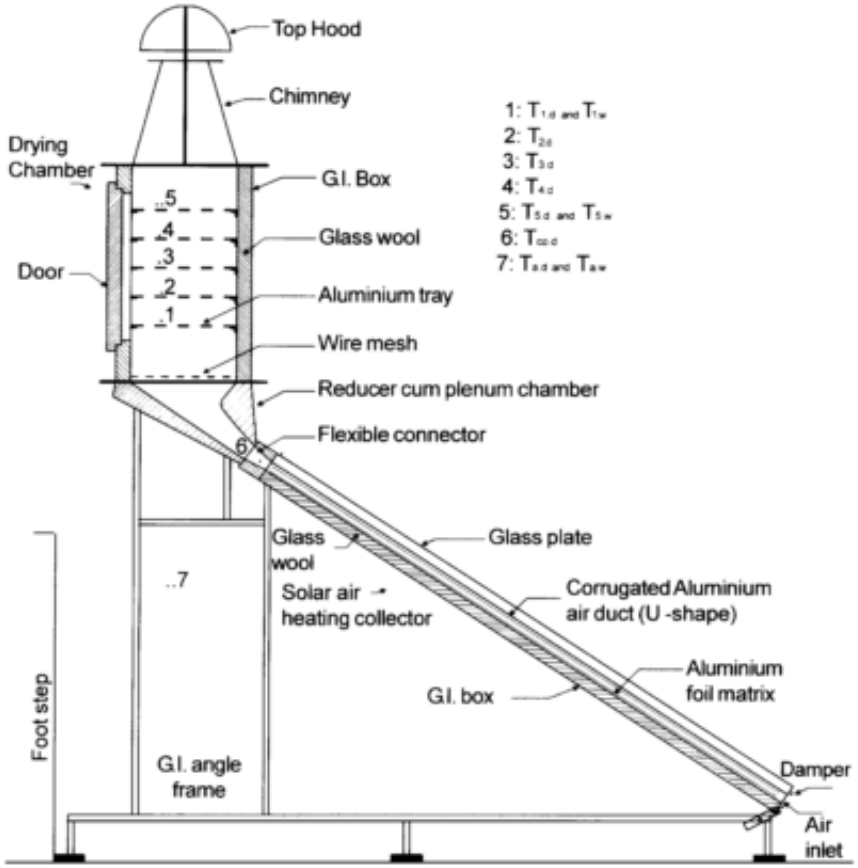
Numbers in parentheses are counts of journal articles with at least one author from the country. (total articles covered ≈ 100; some articles have authors from multiple countries and/or cover both direct drying and indirect/mixed mode drying)

Current Research

Topics

- thin-layer drying models
- nutritional changes in direct-dried products
- comparisons of indirect and mixed-mode dryer designs

Typical Dryer Designs



Pangavhane, D., 2002. Design, development and performance testing of a new natural convection solar dryer. *Energy* 27, 579–590.

Typical Dryer Designs

FIG. 1. ORIGINAL SOLAR DEHYDRATOR BEFORE OPTIMIZATION AND DEVELOPMENT OF A NEW MODEL

characterize and model temperature distribution in cabinet; change inclination of collector and cabinet insulation material

FIG. 4. NEW MODEL OF THE SOLAR DRYER

Sámano Delgado, E., Martinez-Flores, H.E., Garnica-Romo, M.G., Aranda-Sanchez, J.I., Sosa-Aguirre, C.R., De Jesús Cortés-Penagos, C., Fernández-Muñoz, J.L., 2012. Optimization of solar dryer for the dehydration of fruits and vegetables. *Journal of Food Processing and Preservation* – in press.

Typical Dryer Designs: UC Solar Researchers

U.S. Agency for International Agriculture (USAID) / UC Davis
Horticulture Collaborative Research Support Program (Hort CRSP)

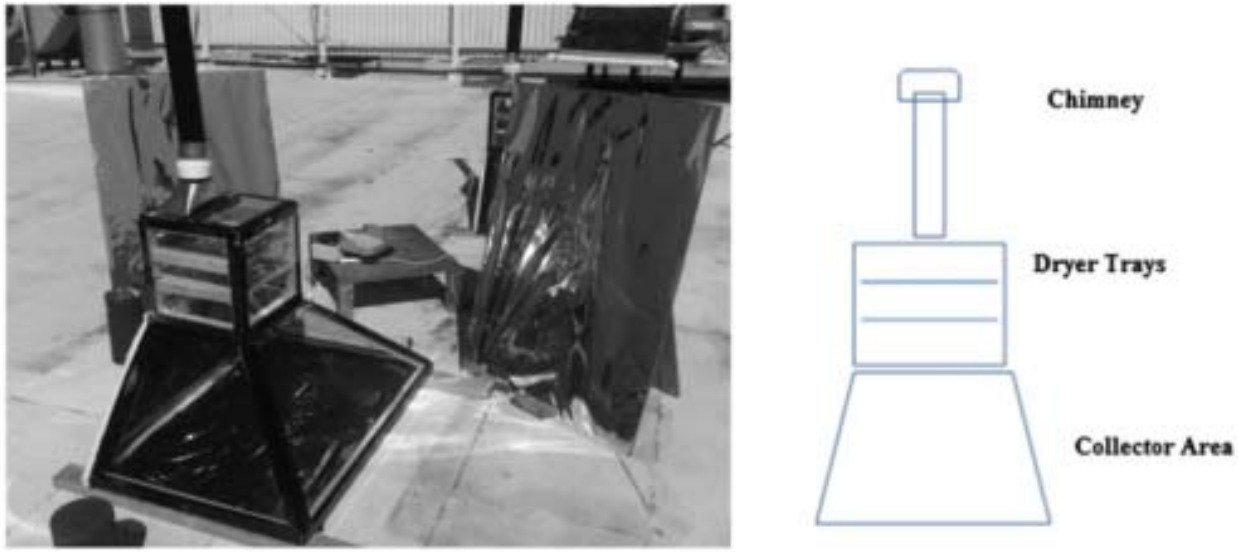


Fig. 1. Solar dryer and two concentrating solar reflection panels used in drying experiments. The data logging instrumentation for the sensors is located on the low table.

→ 3% to 27% decrease in drying time when concentrating solar reflection panels are used

Stiling, J., Li, S., Stroeve, P., Thompson, J., Mjawa, B., Kornbluth, K., Barrett, D.M., 2012. Performance evaluation of an enhanced fruit solar dryer using concentrating panels. *Energy for Sustainable Development* 16, 224–230.

Solar Thermal Drying

2 Parts

Solar Collector
(heats air)

Cabinet
(holds product)

What material(s) should make up the cabinet?

- conventional wisdom: exposure to sunlight degrades nutritional value of the product
- questions: Always? For all products? Must we sacrifice drying speed for product quality?
- What do we already know about the postharvest effects of **artificial** light on fruits and vegetables?

Previous USDA-ARS Research: Infrared Technology

- alternative to caustic peeling of tomatoes[1]
- decontaminate almonds[2]
- high quality dried fruit from simultaneous infrared blanching and drying[3]

1 - Pan, Z., Li, X., Bingol, G., McHugh, T.H., Atungulu, G., 2009. Development of Infrared Radiation Heating Method for Sustainable Tomato Peeling. *Applied Engineering in Agriculture* 25, 935–941

2 - Lin, Y.L., Li, S.J., Zhu, Y., Bingol, G., Pan, Z., McHugh, T.H., 2009. Heat and Mass Transfer Modeling of Apple Slices Under Simultaneous Infrared Dry Blanching and Dehydration Process. *Drying Technology* 27, 1051–1059.

3 - Bingol, G., Yang, J., Brandl, M.T., Pan, Z., Wang, H., McHugh, T.H., 2011. Infrared pasteurization of raw almonds. *Journal of Food Engineering* 104, 387–393.

Previous USDA-ARS Research: UV Treatment

- many Americans are deficient in Vitamin D
- mushrooms are the only vegetarian dietary source of Vitamin D, but they don't produce much of it when grown in the dark
- USDA-ARS developed an ultraviolet (UV) treatment that increases Vitamin D in mushrooms
- partnered with Monterey Mushrooms and the Mushroom Council to implement this technology

Roberts, J.S., Teichert, A., McHugh, T.H., 2008. Vitamin D2 formation from post-harvest UV-B treatment of mushrooms (Agaricus bisporus) and retention during storage. *Journal of Agricultural and Food Chemistry* 56, 4541–4.

UV Treatment of Carrots

photo credit: Roberto Avena-Bustillos

carrot peel to be UV treated (UV-B intensity: 32 milliwatts/cm^2)

Conclusions from Carrot UV Studies

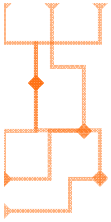
- UV-B doses **increased the total soluble phenolic compounds** 2.5-fold for carrot slices, except by the highest UV-B dose that increased the total soluble phenolic compounds by 6.6-fold.
- **Antioxidant capacity followed a similar trend** to that of total soluble phenolic content for carrot slices exposed to different doses of UV-B.

Avena-Bustillos, R.J., Du, W.-X., Woods, R., Olson, D., Breksa, A.P., McHugh, T.H., 2012. Ultraviolet-B light treatment increases antioxidant capacity of carrot products. *Journal of the Science of Food and Agriculture* 92, 2341–8.

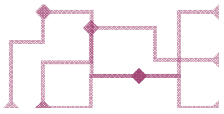
How about natural sunlight?

Goal: Study the effect of different parts of the solar spectrum (UV, IR) on the drying rate and nutritional properties of apricots

[See the Institute of Food Technologists 2013 Annual Meeting poster presentation "Solar Thermal Drying of Apricots: Effect of Spectrally-Selective Cabinet Materials on Drying Rate and Quality Metrics" – Chicago -- July 13-16, 2013.]

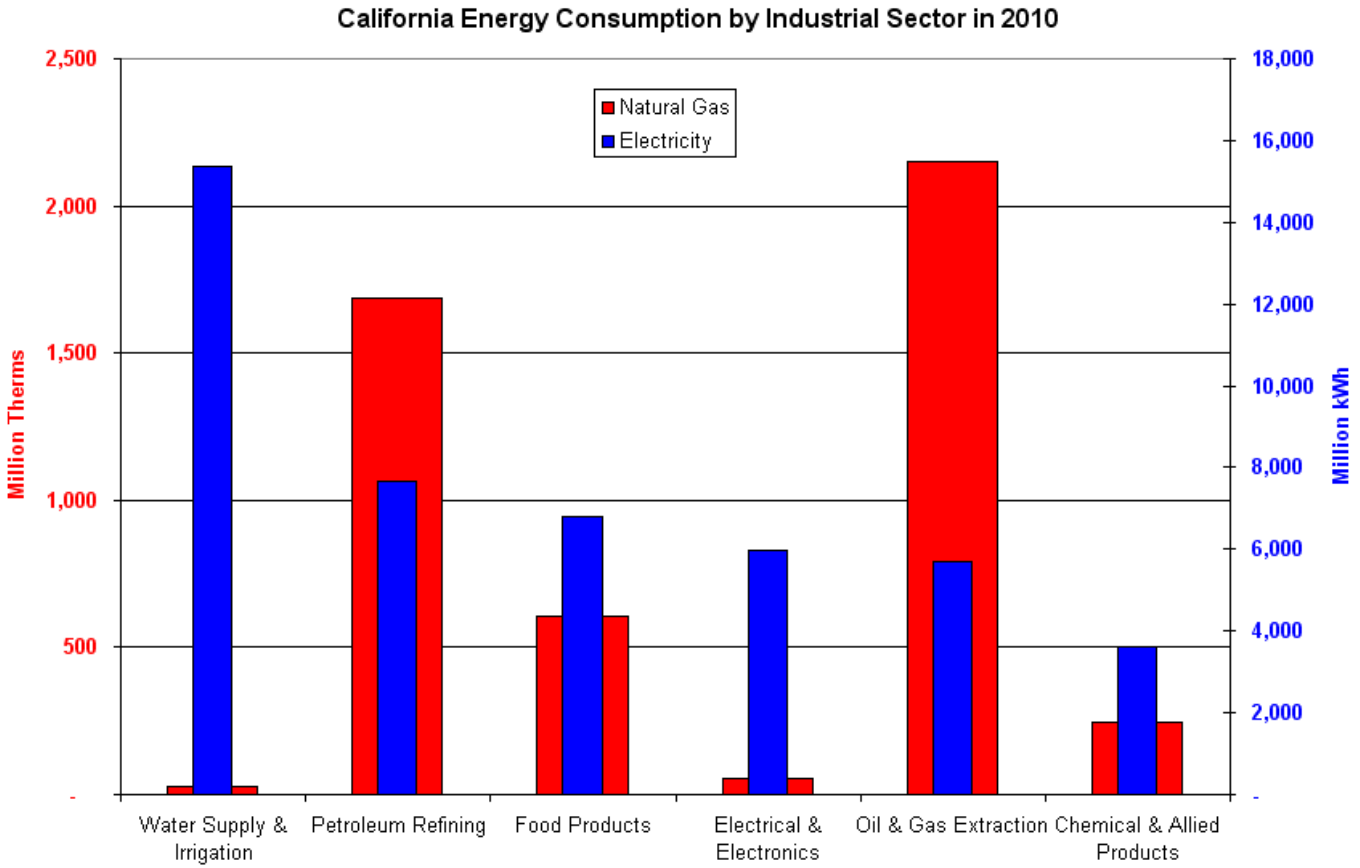


From Old to New
and
Small to Big



Food Processing Industry Share of Energy Use in California

- generates over $50 billion in gross annual revenues[1]
- consumed over 6,800 million kilowatt hours of electricity in 2010[2]
- consumed more than 600 million therms of natural gas in 2010[2]
- 3rd largest industrial energy user in the state[2]



1 - "California's Food Processing Industry Energy Efficiency Initiative: Adoption of Industrial Best Practices" January 2008. California Energy Commission Report 400-2008-006.
available at http://www.energy.ca.gov/2008publications/CEC-400-2008-006/CEC-400-2008-006.PDF

2 and graph – "Quarterly Fuels and Energy Report, December 2012" California Energy Commission Demand Analysis Office

Food Industry Drivers

CA League of Food Processors 2013 Expo

→ 4 of 9 educational/"hot topic" sessions on energy, water heating, CO_2 emissions, or some combination of the 3

→ ~20% of expo exhibitors were in the categories "Energy Service/Suppliers/Technology", "Energy: Solar/Renewable", "Dryers", or "Sterilization/Preservation"

Food Processing Industry = Energy Management Industry

Challenges

- thin margins and desire to cut energy costs
- under pressure to hit greenhouse gas emissions standards from AB 32 (California Global Warming Solutions Act)

Low-Hanging Fruit

- hot process water/steam generation from solar thermal collectors
- process air heating

A Partial List of Solar Thermal Installations at Food Processing Plants in California

- process air heating
  - Sonoma County Herb Exchange (herbs – Conserval/SolarWall)
  - Sunsweet (prune – Conserval/SolarWall)
  - Keyawa Orchards (walnut – Conserval/SolarWall)
  - Carriere & Sons (walnut – Conserval/SolarWall)

- steam and/or hot process water generation
  - PepsiCo/Frito Lay (Sun Chips – Abengoa Solar)
    - 147,000 therms [4.3 million kWh] per year
  - Stapleton-Spence (prune – FAFCO/BCM Construction)
    - 37,500 therms [1 million kWh] per year
  - Williams-Selyem Estate Winery (wine – SunWater Solar)
    - 1,820 therms [53,000 kWh] per year

[much more information available at company and/or solar contractor's website]

Remaining Research Challenges

- short season, 24 hours/day operation (need thermal storage and/or backup heat source)
- existing infrastructure for natural gas- and electricity-driven dryers (need a “drop-in” unit operation solution)
- product safety and quality of paramount importance (need product-specific optimization of processing conditions)

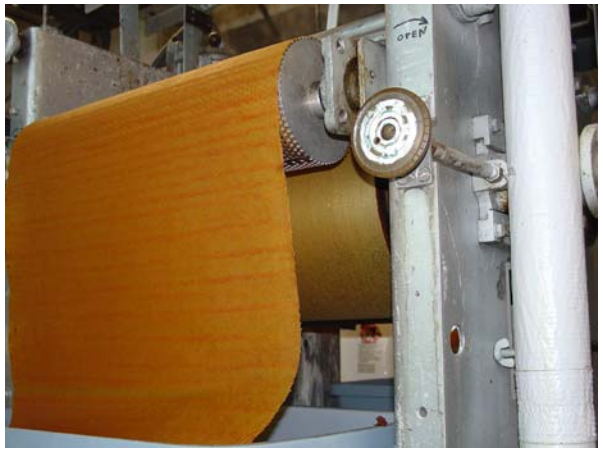
Partnership to Address Industry's Challenges

UC Solar + USDA-ARS

=

Solar Thermal
Specialty Crop Drying
Dream Team

Drum Drying Project



- process is already used for quickly drying fruit/vegetable purees, dairy products, and other pumpable foods

Drum Dryer Designs

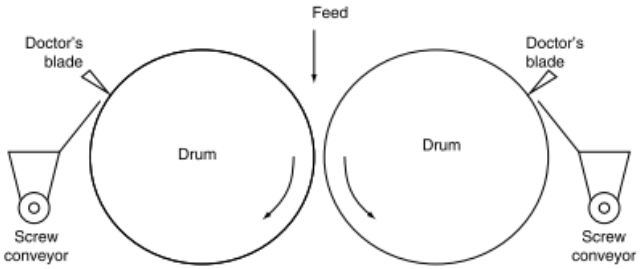


FIGURE 9.1 Double drum dryer with nip feed.

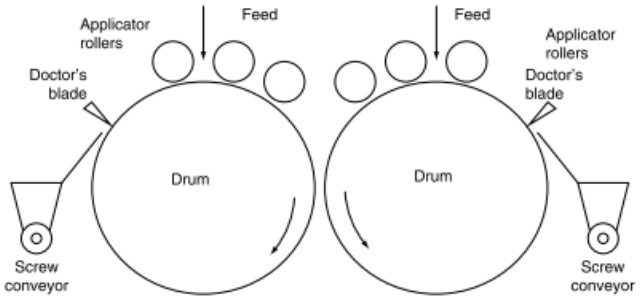


FIGURE 9.2 Twin drum dryer with applicator roller feeds.

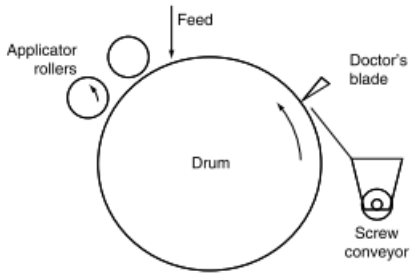


FIGURE 9.3 Single drum dryer with applicator roller feed.

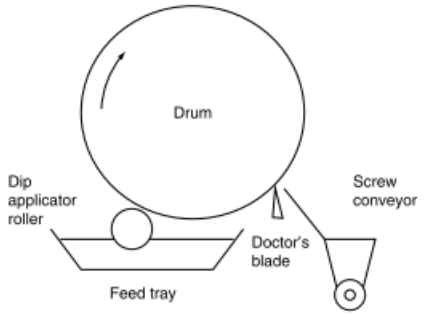


FIGURE 9.4 Single drum dryer with dip roller feed.

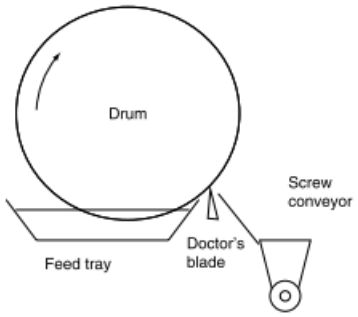


FIGURE 9.5 Single drum dryer with dip feed.

Wan Daud, W.R., 2006. “Drum Drying” in *Handbook of Industrial Drying*, 3rd edition, ed. Arun S. Mujumdar. CRC Press, pp. 203-211

Project Questions

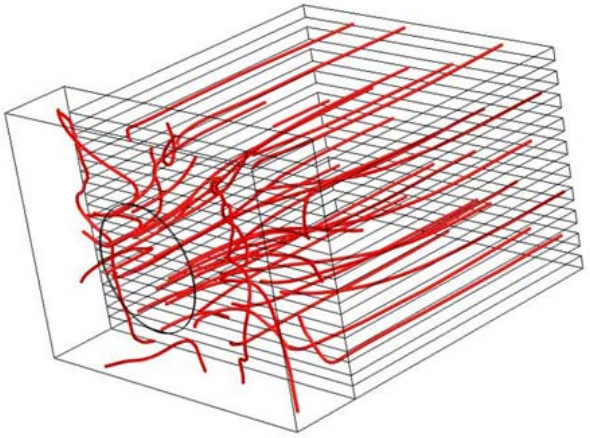
- How can we interface a solar thermal heating system with a drum dryer?
- What are optimal operating conditions for a given puree or pomace*?
  - peach, apple, pear, olive, plum…

→ have applied for a CA Dept. of Food and Agriculture Specialty Crop Block Grant to address these questions and are currently gathering preliminary data

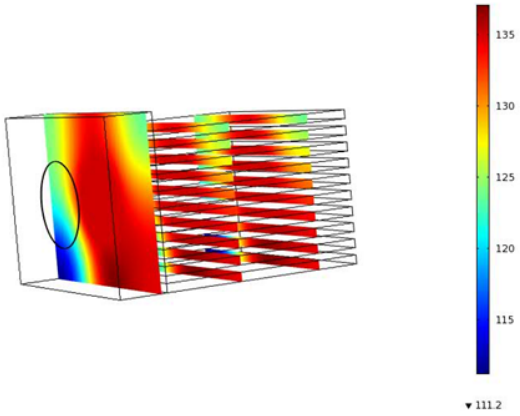
** pomace = co-product of juice or oil production; contains skins, seeds, and fiber; often contains more antioxidants than the primary product!*

There's More…For Later

- multiphysics modeling of solar thermal drying systems



Air Particle Streamlines Through Cabinet



Temperature Distribution Throughout Cabinet, Time = 30 Seconds

Acknowledgements

- USDA-ARS colleagues (postharvest artificial IR and UV)
  - Tara McHugh
  - Zhongli Pan
  - Roberto Avena-Bustillos
  - Wen-Xian Du
- apricot drying experiments
  - Jérôme Alonzo
  - Roberto Avena-Mascareno
  - Carl Olsen
- drum drying project
  - Roland Winston, Bruce Johnston, Bennett Widyolar (UC Solar)
  - Don Olson (USDA-ARS)
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Thank You!

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Recommended Review Articles

- Ekechukwu, O. V., 1999. Review of solar-energy drying systems I: An overview of drying principles and theory. *Energy Conversion and Management* 40, 593–613
  (also Part II and Part III of review in same issue)

- Imre, L., 2006. "Solar Drying" in *Handbook of Industrial Drying, 3rd edition,* ed. Arun S. Mujumdar. CRC Press, pp. 307-361

- Janjai, S., Bala, B.K., 2011. Solar Drying Technology. *Food Engineering Reviews* 4, 16–54