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Sandia National Laboratories

Emissions Abatement of Pepper Roasting Utilizing a Concentrating Solar Tower Thermal Heat Source

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Kenneth M. Armijo, Aaron Overacker, Hector Mendoza, Dimitri Madden, Daniel Ray, Luis Garcia-Maldonado, Kenneth I. Armijo & Randy Montoya

Sandia National Laboratories, Albuquerque, NM

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Agenda

Solar Roasting Challenges

- Carbon emissions abatement utilizing concentrating solar power (CSP) heating for culinary industrial process heat applications of roasting peppers.
- Arid regions with high energy demand for cooking, traditional "hot-box" cookers or solar ovens employed w/solar reflective surfaces.
- Limited solar thermal cooking methods for roasting temps > 450C.

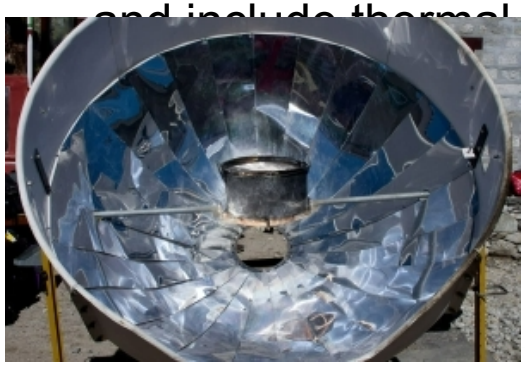
Overview

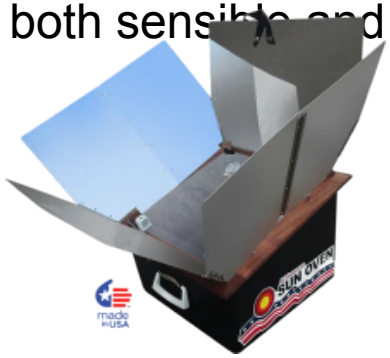
- Roasting & Emissions
- Solar Tower Experimental Setup
- Experimental Facilitation
- Analysis & Results

Conclusions & Future work

Food Roasting & Peppers Overview

- Traditional Capsicum Annuum "Chile" pepper, typcially roasted for a vareity of cultural food.
- Roasting of Chile peppers typically preferred for flavor preservation & culinary preparation for processes that release natural flavor compounds.
- Fruits and vegetables can contain over 80% moisture, cooking/dehydration down to 5-10% moisture levels can be energy intensive
- Traditional concentrated solar cookers can achieve temperatures of up to 300°C, and include thermal energy storage (TES) for both sensible and latent forms



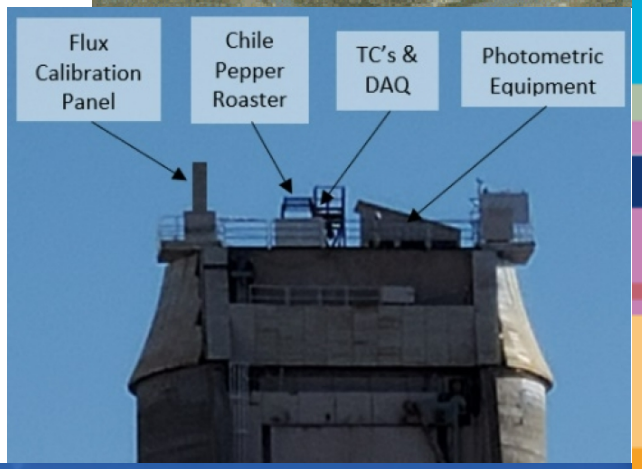


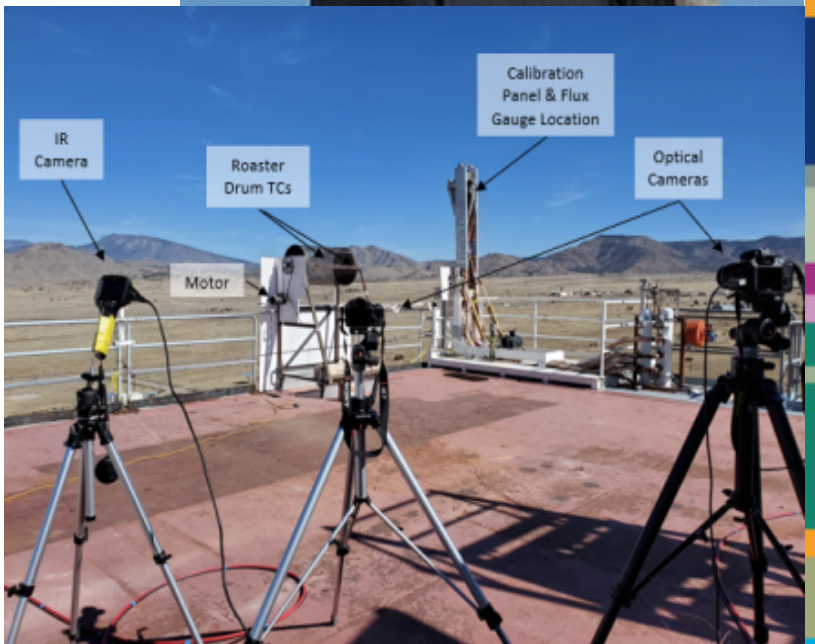
Capsicum Annum "Big Jim Chile" Peppers

Food Type	Approx. Cooking Temp.	Ref.
Rice, Lentils, Potatoes	43°C	Prande et al., 1987
Meat	120°C	Mussard et al., 2013
Coffee	125°C	Kamboj et al., 2017
Cashews	130°C	Lainas et al., 2016
Almonds	146°C	Lainas et al., 2016
Wheat	180°C	Schoeman et al., 2019
"Chile" Peppers	550°C	Current Meas., 2021

Experimental Setup

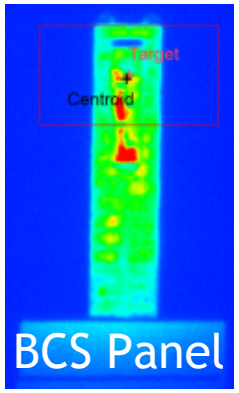
- Sandia National Solar Thermal Test Facility (NSTTF)
  - 35-42 heliostats used (of 218 total)
  - ~200 ft tall tower with 6 MW_{th} potential
- Standard pepper rotational roasting drum (0.6 m diameter by 1.2 m length)
- RSLE insulation used to protect roaster motor and calibration system lines and DAQ
- Each roast contained ~10 +/- 0.01 kg determined based on load constraints of system motor and chile roasting best practices for drum size.
- State properties calculated at inlets/outlets along both hot/cold legs of

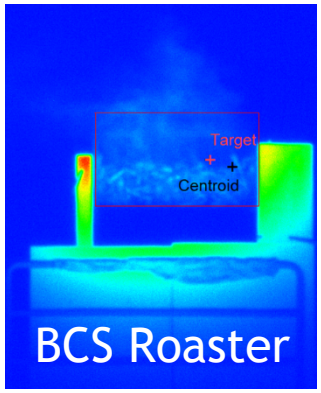


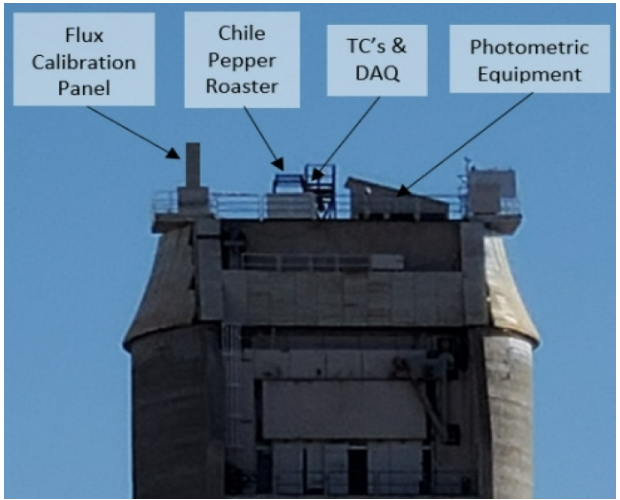


Preliminary CST Calibrations

- Preliminary TC drum roaster measurements calibrated with IR.
- Initial flux and No. of Heliostats determined based on ground-based IR measurements.
- BCS calibration panel using Kendall, temp. compensated radiometer.
- BCS Centroid software used for flux profile averaging: For Panel and Roaster.
- 550-600°C target temperatures equated to 35-42 heliostats for 12-18 W/cm^2 flux.
- Rotational speed determined based on best practices for determining char profile.

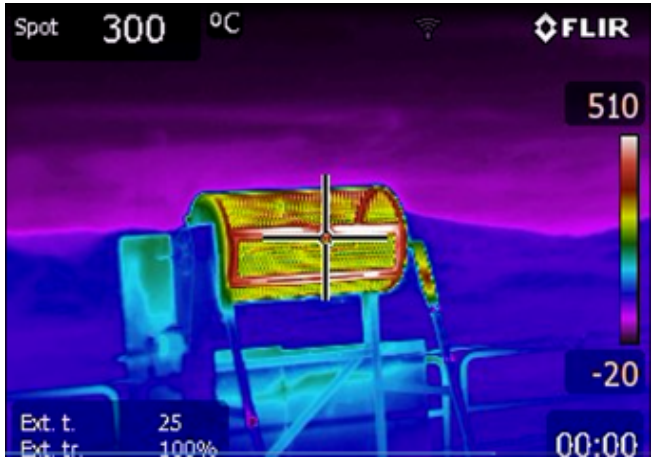






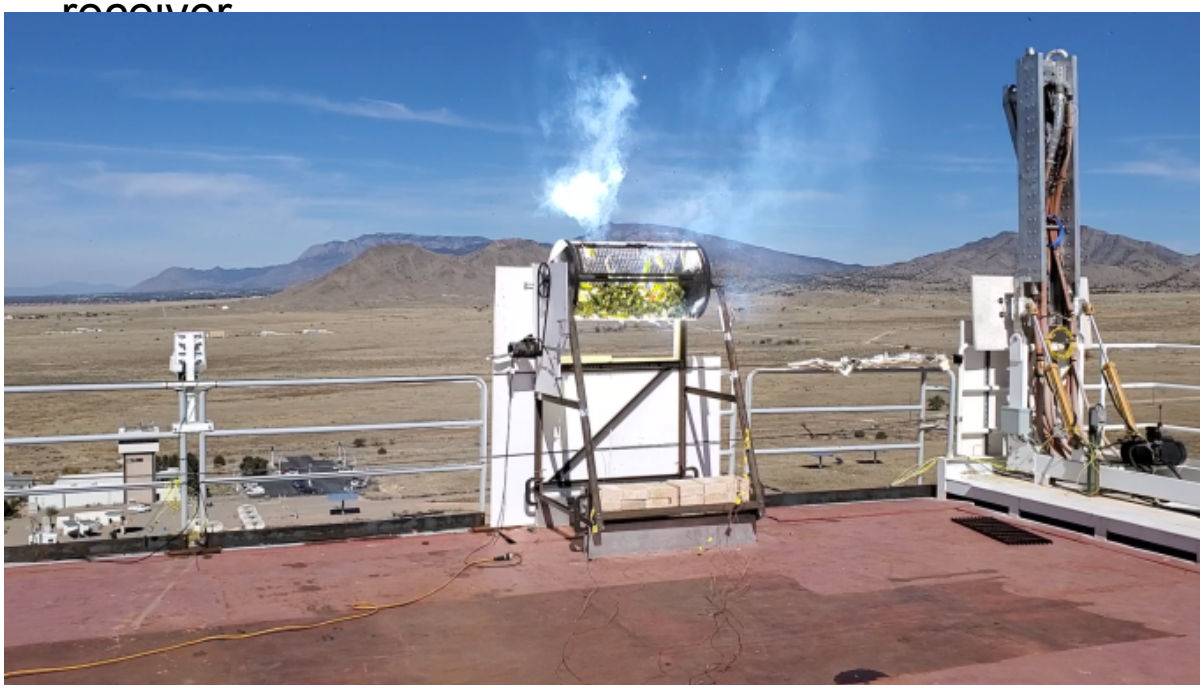
Ground-Based Traditional Roasting

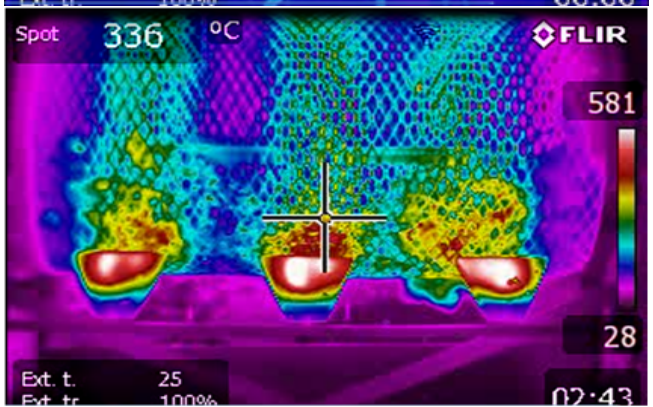
- Results indicate receiver peak flux increases for uniform flux distribution & tube geometry.
- Weight scale used to assess volume of propane used over time, where with Temp. convolvement total emissions could be determined.
- Burners roasted in more surface, localized heating manner.
- IR values found to vary between approximately 580°C at the outer surface of the drum to approximately 200°C within the bulk pepper volume between burners.



Tower-Based Roasting

- Liquid receiver design with tube size of ½ NPS Sch.10 billboard receiver orientation.
- Pressure drop allowed will range from 0.1 bar/m to 0.5 bar/m resulting in expected mass fluxes between 3000 kg/m^2 and 10000 kg/m^2.
- Resulting heat transfer coefficients range from 8,000 to 20,000 W/m^2-K, chloride salts ranging from 3,000 to 9,000 W/m^2-K, and sodium ranging from 30,000 to 60,000 W/m^2-K.
- Nitrate salt receivers can potentially reach between 85% and 95% efficiencies & ternary chloride salt will be limited to between 80% and 90% efficiency.
- Sodium receiver efficiencies between 90% and 95% provided sufficient flux to receiver.





Comparisons & Results

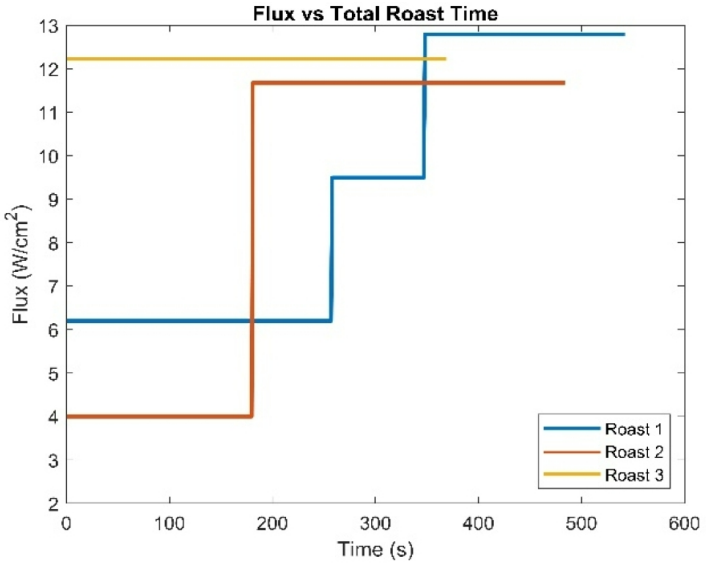
- Six roasts total were conducted for data collection, three with conventional propane burner and three using CST.
- Second roast used unwetted chile, so a shorter test duration was required at a lower flux.
- By final roast, an optimal flux level for roasting had been determined & used for duration of roast. This accounts for the shortened roast duration between subsequent CSP experiments.

Propane Summaries

	Roast Duration (Seconds)	Mass loss of Propane Tank (kgs)
Propane Roast 1	251	0.527
Propane Roast 2	195	0.426
Propane Roast 3	256	0.512

Overall Roasting Summaries

	Maximum temperature (°C)	Average Solar Flux (W/cm^2)	Test Duration (Seconds)
Baseline Propane Roast	581	N/A	180
CSP Roast 1	464	9.123	542
CSP Roast 2	510	8.823	484
CSP Roast 3	490	12.230	369



Comparisons & Results Cont'd

- Results found that roasting peppers with CSP facilitated approximately 26 MJ of energy that abated approximately 0.122 kg CO_2/kg peppers for a 10 kg bag.
- With CSP emissions could be abated up to 0.131 kg CO_2/kg.
- NM produced 6.169 million kilograms of Chile peppers in 2020, which amounts to potential abatement of 808,139 kg CO_2 (~1.78M lbs CO_2).
- Results determined 2.99 kg-CO_2/kg-propane based on EIA value of $1.92/gal. of residential propane, cost of fuel abated could result in financial impact of 2.28 million USD.

$$Energy\ (kWh) = Flux\left(\frac{kW}{cm^2}\right) * area(cm^2) * duration(h)$$

$$Emissions\left(\frac{kg\ CO_2}{kg\ chile}\right) = \frac{Emissions\ (kgCO_2)}{chile\ bag\ mass\ (kg)}$$

$$Emissions\ (gCO_2) = Energy\ (kWh) * \frac{38gCO_2}{kWh}$$

	Average Solar Flux (W/cm^2)	CSP Roast Emissions (kg CO_2/kg chile)
Roast 1	9.123	0.0304
Roast 2	8.823	0.0263
Roast 3	12.230	0.0278

	CSP Roast Emissions (kg CO_2/kg chile)	Propane Roast Emissions (kg CO_2/kg chile)	Emissions Abated (kg CO_2/kg chile)
Roast 1	0.0304	0.1576	0.1272
Roast 2	0.0263	0.1274	0.1011
Roast 3	0.0278	0.1648	0.1370

Culinary Quality Survey

- Likert scale participant survey conducted pertaining to varying qualities between CST-roasted peppers versus traditional, propane-roasted peppers.
- Charring profiles for all propane-based, and solar tower experiments were relatively similar
- Questions ranged across flavor, smell, peel-ability, texture
- On average, the surveyed respondents favored the solar tower-roasted peppers over the propane-roasted peppers by 18% for flavor, 2% for peel-ability and 12% for smell.
- Post-test texture however, respondents actually favored the propane-roasted peppers by a small margin of 4%.

	Not Very Satisfied - 1	Satisfied - 2	Nuetral - 3	Satisfied - 4	Very Satisfied - 5
Solar Tower-Roasted: **Flavor**	0%	0%	0%	21%	79%
Propane-Roasted: **Flavor**	0%	7%	7%	57%	36%
Solar Tower-Roasted: **Smell**	0%	7%	14%	50%	21%
Propane-Roasted: **Smell**	0%	21%	21%	29%	14%
Solar Tower-Roasted: **Peel-ability**	0%	7%	36%	21%	29%
Propane-Roasted: **Peel-ability**	7%	14%	0%	50%	29%
Solar Tower-Roasted: **Texture**	7%	0%	21%	50%	21%
Propane-Roasted: **Texture**	0%	7%	21%	43%	29%

Conclusions & Future Work

- Solar tower chile pepper experiment conducted as comparison against traditional propane gas roasting.
- Overall results suggest that comparable solar roasting to traditional propane roasting is possible up to flux levels of 18.7 W/cm2 for 3-4 minute durations.
- CSP roast had a more uniform temperature roast distribution.
  - Use of water cleaning added more time though improved uniform volumetric heating
- Based on calculated 2.99 kg-CO2/kg-propane and EIA value of $1.92/gal cost of fuel abated could also result in a financial impact of 2.28 million USD.
- NM produced 6.169 million kilograms of Chile peppers in 2020, which amounts to potential abatement of 808,139 kg CO2 (~1.78M lbs CO2).
- Propane-based experiments generally included more charring than the solar-based experiments
- Survey results overall appeared to favor CST-roasted peppers for its ability to have a cleaner, less smokey flavor, while allowing an easier, more timesaving peeling process.
- Future work will be required to obtain a larger statistical sampling of survey

Acknowledgements

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kmarmij@sandia.gov

Thank you.