Solar Powered Dehydrator

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Abstract

A research project initiated after a faculty trip to a rural community in the Zacapa region of Guatemala. Much of the fruit that could be harvested and sold goes to waste, as too much becomes ripe simultaneously. One solution that is being explored is dehydration. The fruit can be dehydrated prior to rotting, which extends its shelf life, as well as facilitates it being sold in other areas. Modifications were made to an adopted design to accommodate the location of the use. The dehydrator uses natural solar energy to heat a chute and uses convection to provide hot airflow through an area that contains racks of fruit. The dehydration process and overall dehydrator design is an optimization problem between heat and airflow. Once faculty have finalized the preliminary design, students will be assigned projects in multiple classes to optimize different aspects of the design and help generate feasible business models for implementation. This paper will discuss how this research to application model can be used for other similar projects using best practices for project-based learning in the classroom.

Keywords

Project-based learning, Fruit dehydration, Solar power

Introduction

As is a requirement in many engineering programs throughout the world, the Mechanical Engineering Department at The Citadel requires seniors to complete a 2-semester design project (capstone), in which they develop a solution to a customer-based design problem. The student design teams work through the engineering design process to identify a problem, determine customer requirements, analyze the market, design concepts, perform engineering calculations and simulations, and create prototypes in order to generate a complete product design. These projects are generally proposed by various faculty within the School of Engineering who often advise the projects through their completion. Projects span a variety of different subject areas, as long as the final deliverable is construction of a thermal or mechanical system. For example, previous projects have included a wind powered land yacht, a solar powered water collector, an infrastructure inspection robot, and a Baja SAE vehicle. Many engineering students are interested in using their engineering background to improve society, supported by student engagement in programs like Engineers Without Borders, Penn State's Humanitarian Engineering and Social Entrepreneurship Program, the University of Colorado's Mortenson Center in Global Engineering, and Clemson Engineers for Developing Countries.[1-4] These types of experiences that are relevant to satisfying students' personal goals can help drive motivation, based upon Vanasupa et al.'s description of the "value" construct of motivation.[5]

Additionally, there are occasionally opportunities for faculty to use these senior design projects to further their academic research. A team of faculty members at The Citadel are pushing forward with a research agenda and program in humanitarian development, which included an exploratory trip to rural Guatemala in January 2020. Figure 1 shows an abundance of mangos at the local market.

Figure 1: Abundance of mangos (Samuli Kangaslampi Flickr (CC BY-NC-ND 2.0))

During this trip to the Zacapa region of Guatemala, community members discussed with faculty the prevalence of food loss. In particular, at harvest time more fruit becomes ripe than is able to be immediately sold or shipped out for sale and ends up rotting. This is not unique to Guatemala. In fact, in most areas of the world, food loss from post-harvest to distribution exceeds 10%, and in some developing regions, the value is over 20%.[6] A recent study on mango loss in East Africa provides an additional data point for losses in developing regions, with an estimated post-harvest loss of 40-50% in Kenya.[7]

Upon return to the United States, given this food loss, team members performed a literature review to better understand the context of the problem, as well as potential solutions. Team members have developed a foundational prototype for a solution, and this paper describes that solution, as well as how faculty intend to create and assess the impacts of a unique situation in which multiple senior design projects will contribute to a greater system, within a single class.

Proposed Solution

Food loss can be attributed to three broad categories, including:[6]

1. On-farm post-harvest/ slaughter operations
2. Transport, storage, and distribution
3. Processing and packaging

The food loss described by community members could potentially be attributed to one or more direct or indirect drivers, including:[6]

- Poor harvest scheduling
- Lack of proper storage or transportation facilities
- Poor management of temperature or humidity
- Prolonged storage (e.g. due to lack of transportation)
- Logistical mismanagement (poor handling of delicate produce)
- Inadequate processing capacity for seasonal production gluts

This list highlights the fragility of fresh produce and the constraints under which the farmer is working to produce a profitable crop. A variety of solutions exist to potentially address these issues, but many prospective solutions (e.g., purchasing additional transportation) are cost prohibitive to the farmer. The research team, in coordination with Guatemalan counterparts, began exploring preservation techniques, and eventually decided to develop a food dehydrator to prolong the shelf life of the produce and increase its transportability. Though dehydrated food may not be culturally desirable in all circumstances, it would allow for food to be preserved and exported rather than end up as a loss.

Solution Design

Due to the unavailability of reliable power in many of the regions in which this food dehydrator would be used, one of the primary design constraints was that it could not require electricity. The literature describes different systems that meet these criteria, using heat sources generated from a wood-fired furnace, direct solar energy, indirect solar energy, photovoltaics, other means, or a combination of these heat sources.[8-10] As one of the more commonly referenced and replicated designs, and due to its low cost, low maintenance requirements, and widely available material requirements, the research team decided to use a modified version of Scanlin's 1997 design[11-12] as the foundation for this project.

The research team began modifying and constructing the solar food dehydrator in Spring 2020. The design consists of two primary components: a solar collector and drying chamber. The solar collector is an 80"x38"x11" wood framed box, with plywood sides and a clear polycarbonate top. The interior of the sides and bottom are covered in polyisocyanurate foil-faced rigid foam insulation board to improve insulation and maximize solar collection potential. The solar collector itself resides within the solar collector box and consists of a dark colored aluminum screen. It is installed at an angle such that it collects solar energy and natural convection causes air to pass through the screen, absorbing heat that is then passed into the drying chamber. The solar collector was angled at 20 degrees from horizontal and faced south to maximize solar collection at the dehydrator's latitude, as calculated from NOAA's Earth System Research Lab's Solar Position Calculator.[13]

The drying chamber consists of a 39"x25"x40" plywood box with wooden shelves, holding drying racks. The most economical solution for drying racks that met the expected requirements was to use cooling racks intended for baking. The interior of the box is painted with a mold and mildew resistant paint. Two adjustable vents were installed at the top of the drying chamber. By opening the vents, the user can increase air flow and decrease temperature, or conversely, closing the vents increases temperature but slows (or stops) air flow through the drying chamber. Air gaps found in the solar collector, drying chamber, and connection between the two were sealed with latex caulk. The solar dehydrator, as constructed, and the original design[12] are shown in Figures 2 and 3, respectively.

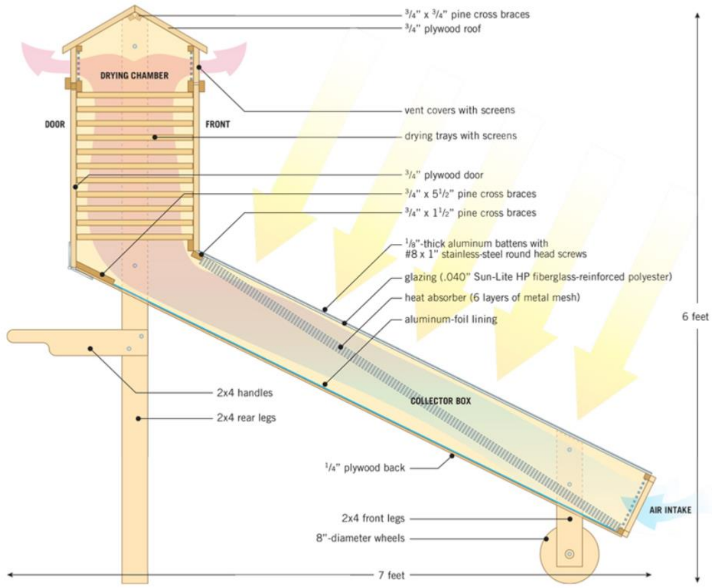

Figure 2: Constructed dehydrator **Figure 3**: Original design[12]

The thermocouple locations include the inlet and outlet of the solar collector, on the bottom, middle and top of the drying chamber box. Data collection started in July in Charleston, South Carolina. In Charleston in July, the average high temperature and relative humidity is 91.1°F and 76.6%, respectively.[14] The thermocouples maxed out due to the equipment getting too hot. While temperature and humidity data collection occurred, the data is sporadic. A priority for the team is to purchase anemometers that can reliably handle the conditions. Temperature for fruit dehydration is between 110°F and 140°F.[11] The temperature data collected included multiple times at 110°F and above. Humidity is a variable that needs to be analyzed in more detail. Based only on the research team tastes, the fruit that was dehydrated was chewy. This is thought to be because of the high humidity values.

Senior Design Utility

As previously discussed, this design will serve as a baseline for further refinement and testing. Design modifications and additions will be made for potential efficiency improvements, cost reduction, improved testing capability, and increased available operating time. The results of modifications will be compared to results from the baseline design to determine efficacy of the proposed solutions. A variety of senior design project prompts will be developed to optimize and refine individual components and subsystems of the holistic solar dehydrator. Because the results of the senior design projects may impact one another with regards to introducing new constraints, changing geometry of the overall system, or otherwise modifying operation of the system, senior design teams must coordinate with one another to determine how their projects will interact with other projects.

Stemming from the baseline dehydrator design, potential branches for senior design projects include the following:

- Solar Collector angle optimization - The current design, as described above, placed the collector at an angle which should maximize solar collection at the location latitude. This angle has merely been calculated not optimized based on measurements with the collector. Moreover, the current design does not allow for a change in this collector angle without significant construction. To avoid reconstruction or non-optimized collector angling, students could design a straightforward experiment using solar cells to optimize the collector angle for the given location. This experiment could be run at the dehydrator location prior to construction; the results would then dictate the exact collector angle at the given location.

- Automated solar tracking- Solar collection depends on the positioning of the solar collector with respect to the sun. Students will design and construct a mechanism to track the sun during daylight hours so that solar rays are as close to perpendicular to the solar collector as feasible.

- Automated vents- During the dehydration process, system conditions are expected to be variable. External variables include temperature, humidity, cloud cover, and solar position. Internal conditions, such as moisture content of fruit in the drying chamber, drying chamber and solar collector temperature, and humidity in the drying chamber, will also vary during the dehydration process. Students will design and construct automated vents that can open or close based upon desired internal parameters or external triggers.

- Anemometer- The research team had difficulty finding appropriate anemometers for system testing. For field deployment, users may want to optimize their system after site installation. Students will design and construct an anemometer meeting the requirements for the system.

- Supplemental heat system- Since the dehydrator system uses solar energy as the sole heat source for the process, cloud cover, rainy weather, excess humidity and low temperature, and other scenarios may prohibit use of the system. Students will design and construct a supplemental heat system that can use the existing drying chamber in the event of impractical conditions for dehydration using only solar energy.

- Redesign for material optimization- The solar dehydrator is intended to be used in low-resource environments. The existing system was designed for testing purposes, without full consideration of materials used in construction. Students will redesign the solar dehydrator with primary respect to materials use, considering material availability, material quantities, material cost, durability, and environmental impacts of materials.

- Design improvements to minimize footprint - The current solar collector box design has not been optimized and currently has a large footprint. It is possible that this size could pose a challenge for placement or for material costs. Students will brainstorm and design a new solar collector box that optimizes the heating, air flow, size, and material costs.

Due to the context of the intended use, in addition to pure functionality, all student design should weigh other relevant variables in their design, including upfront and lifecycle costs, availability of materials, repairability, and operations and maintenance requirements.

Discussion

Creating multiple senior design projects all focused around one core technology can have both benefits and drawbacks, as the convergent approach can provide new challenges that require better coordination and communication among students and faculty.

As for primary benefits of this approach, authors hypothesize that the implementation of these overlapping projects have the potential to provide more thematic projects and sections which could serve to better engage students along different projects, building a stronger common knowledge base. It is expected that the student teams would benefit from having multiple students researching aspects of a single engineering challenge. Additionally, previous research at The Citadel has shown that competition among teams improves motivation and progress.

Another benefit would, of course, be to advance faculty research in an area of practical, humanitarian interest. Projects with implications to solving societal needs are of particular interest to faculty and students alike at our institution. Pursuing congruent, simultaneous projects would also result in the development of a more complete, better functioning dehydrator as multiple issues would be resolved.

With regards to challenges, before the proposed senior design projects could be used to optimize the design, an optimized baseline prototype needs to be completed. While the team has currently constructed a viable design and made initial measurements, a standard, reproducible baseline prototype with superior function needs to be finalized. This requires more faculty pre-work than a traditional capstone experience, and it may not work well depending on the stage of the applied research.

Additionally, while each team would be focused on the specific outcome, the individual solutions would need to work well with the other teams. Communication and coordination would be required to avoid conflicts in the solutions to ensure that the solutions will integrate with one another, but this is a realistic concern for practicing engineers.

Path Forward

Senior design projects for the 2021-22 academic year will be selected in a few months. Multiple projects, as detailed above, will be proposed for inclusion.

Additionally, as summer 2021 internship opportunities are still unclear due to COVID complications, it is possible that a number of engineering students will be applying for institution-sponsored summer undergraduate research projects. If multiple students secure this funding, multiple projects will be pursued by the faculty and students.

Faculty will continue developing the relationships with partners in Guatemala, particularly those in communities where the dehydrator(s) will be located. This will allow more fluid communication between students and developing communities, which will provide more genuine stakeholder feedback and engagement, which will benefit both parties involved. This will also allow the field-implementation of the project to be monitored and assessed more closely.

Finally, faculty will develop a survey tool to assess whether this convergent capstone project approach creates a significant difference in student motivation, collaboration, cross-team communication, perceived project value, and systems thinking as compared with traditional one-off capstone projects.

Conclusion

This work was conceived after observing the significant loss of Guatemalan produce and income incurred due to complications including an overabundance of ripe fruit in a short time period and geographical barriers to easy transport. A solar power fruit dehydrator has been built as an initial solution. A multi-prong research approach, through concurrent engineering senior design projects, would optimize the design and effectiveness. Not only would this coordinated project-based learning advance the solar fruit dehydrator design, it would improve student understanding of both the constraints of a different culture and of systems-based engineering solutions.

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Emily Bierman received her B.S. in Mechanical Engineering from Purdue University, her M.B.A. from Clarke College, her M.S. in Mechanical Engineering in Engine Systems (MEES) from University of Wisconsin, and her Ph.D. in Mechanical Engineering from North Carolina State University. She completed internships at Caterpillar, Ford and GM. She worked for John Deere in the Construction and Forestry Division as well as the Power Systems Division. She worked for Cummins in the High Horse Power group for two years. She is now an assistant professor in the Mechanical Engineering Department at The College.

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Deirdre Ragan is an Assistant Professor in the Department of Mechanical Engineering as well as the Director of the Honors Program at The Citadel. She holds a B.S. in Materials Science and Engineering from Rice University as well as a M.S. and Ph.D. in Materials from the University of California Santa Barbara where she studied stresses in thin films. Now she enjoys teaching upper-level undergraduate and graduate Materials courses and encouraging students in research. Her research interests include materials science, cognitive curiosity, humanitarian engineering, and undergraduate research involvement.

Aidan Fillippa

Aidan Fillippa is a high school student in Charleston, SC. He enjoys building things and getting out of the house, especially as COVID limited his options. He enjoys research, problem solving, and traveling and, through this project, has grown in his appreciation of humanitarian engineering.