Analysis of Crop Dryer Recirculation and Heat Recuperation

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INTRODUCTION

Walnut dehydration is a service performed for walnut growers as an extension of the harvesting process. Walnuts are processed and then placed in bins to be dried to the right moisture content using hot air. The dryer intake air is heated using propane or natural gas burners and the associated fuel costs tend to be a significant portion of the operating costs of a dryer. Figure 1 shows a typical dryer bin setup with exhaust air flowing up through the walnuts and out into the atmosphere.

Figure 1. Typical Dryer Setup (Tule River Dehydrator, 2013).

The hotter the intake air being drawn into the burners, the less fuel is consumed to heat the air to an adequate temperature. This concept is understood by many operations which only run dryers during daylight hours to save fuel. With the recent increase in crop volume due to higher nut prices, this method of optimizing efficiency is no longer possible since many operations are running at full capacity. This requires the dryers to run throughout the night during the cooler hours. Many operations are now using exhaust air recirculation to achieve the same effect on efficiency. The hot exhaust air leaving the bins is humid but retains some moisture carrying capacity. The air is typically wasted to the atmosphere. Recirculation systems reroute this air back into the dryer intake in various amounts. This project will analyze the feasibility of recirculating exhaust air back into dryer intake and recuperating waste heat to increase dryer efficiency and lower fuel costs. Optimum recirculation amounts during different stages of the drying process will also be determined.

LITERATURE REVIEW

Design Research

Dryer Burner A Peerless Jet Dryer will be used for testing during this project. This dryer is manufactured by Peerless Manufacturing located in Shellman, Georgia. Two models will be discussed:

Figure 2. 5-7HP 22" Jet (Peerless, 2014).

Figure 3. 5-7 HP 24" Whisper Single (Peerless, 2014).

These dryers are compact and portable which make them ideal for the purposes of this project. The main difference between the two models is that the Jet (Figure 2) uses a high RPM axial fan that is very loud and the Whisper (Figure 3) uses a centrifugal fan to move the same amount of air but with much less noise. These models use a temperature probe and a thermostat to monitor and regulate air temperature by regulating fuel flow. The warmer the intake air, the less gas is used for heating. (Peerless, 2014)

Recirculation System Recirculation systems have been implemented with varying levels of success in the walnut drying industry. The idea is to utilize the waste heat in the air and its residual moisture carrying capacity. The optimum level of recirculation changes throughout the drying process as shown in Figure 4.

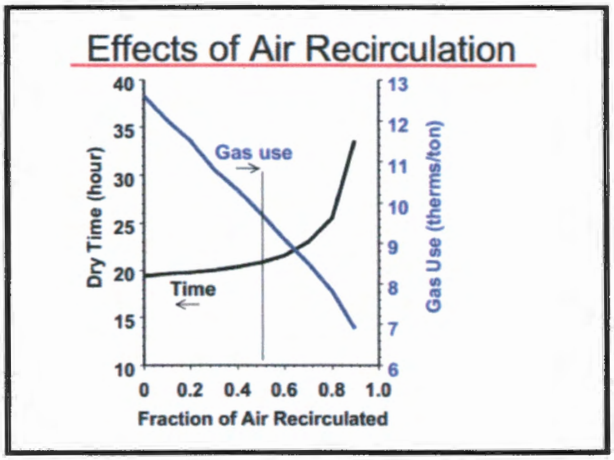

Figure 4. Recirculation Effects Curve (UC Davis, 2009).

It is a common misconception that recirculation is useless because moisture inevitably builds up inside the building. The moisture problems are not inherent to recirculation but rather result from improper atmospheric separation of the intake area. Some indoor dryers have been built with the intent of utilizing recirculation but have had one major design flaw. These facilities experience extreme moisture build up inside the dryer area and typically vents are cut into the roof to alleviate the problem. This effectively renders the newly built dryer incapable of recirculation. After conducting this research, it appears that the problem is that these dryers are built without a wall of separation between the bins and the intake for the burners with a gap near the roof as illustrated in Figure 5. The wall prevents cold moist air from recirculating back into the burners and only allows the warmest air near the ceiling to circulate to the intake side of the wall. (UC Davis, 2009)

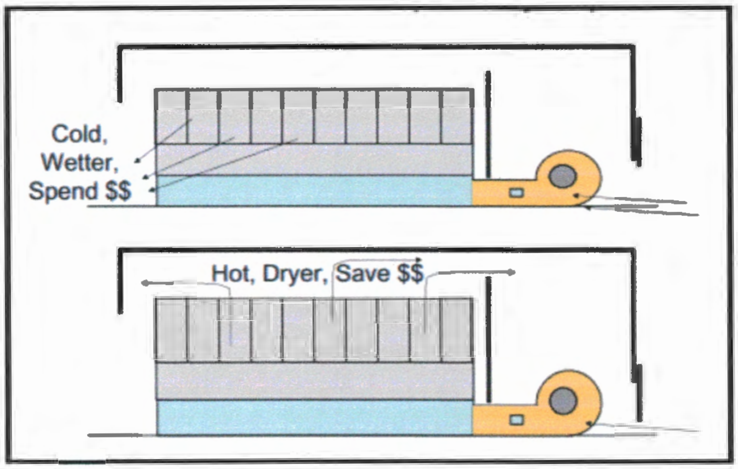

Figure 5. Proper Recirculation Design (UC Davis, 2009).

Recirculation will be controlled using ducting for this project. All exhaust air, even exhaust air that is not recirculated, will pass through a heat exchanger to recuperate waste heat.

Heat Exchanging System This project will utilize the heat exchanging properties of a cross flow recuperator. A recuperator is a device that allows heat to be exchanged between two fluids. This concept is illustrated by Figure 6. Warm air passes through and warms a core before it is expelled from the system. Cool intake air is warmed by the core as it passes through on its way to the dryer. The two airflows never touch or contaminate each other. Eclipse Manufacturing and other companies sell devices like the one in Figure 7 that would work with a variety of air flow rates. (Eclipse, 2014)

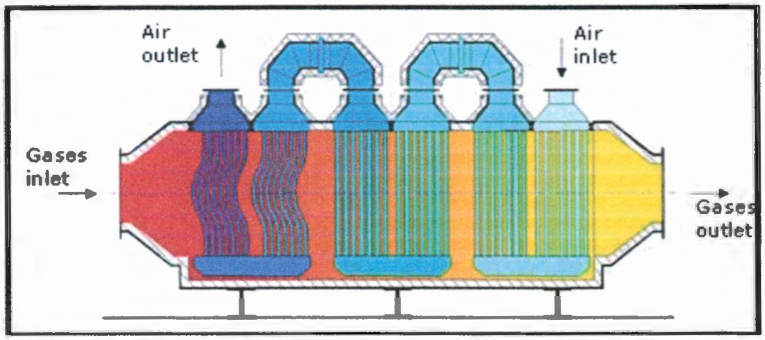

Figure 6. Typical Recuperator Design (Kalfrisca, 2014).

Figure 7. Eclipse Cross-Flow Recuperator (Eclipse, 2014).

A device like this could be used to recuperate some of the heat from the exhaust air coming from the dryer bins. This air must be ventilated to prevent moisture accumulation but the heat could be extracted first and could be utilized to further improve dryer efficiency.

PROCEDURES AND METHODS

Measurements and Data Acquisition

This first thing that must be done for this project is to collect data and measurements of the crop dryer to be used and its placement in the drying operation. The Peerless dryer rests on a concrete pad that sits next to the dryer bin. Figure 8 below shows the concrete pad to scale and the available space on the pad next to the dryer for placement of the recuperator.

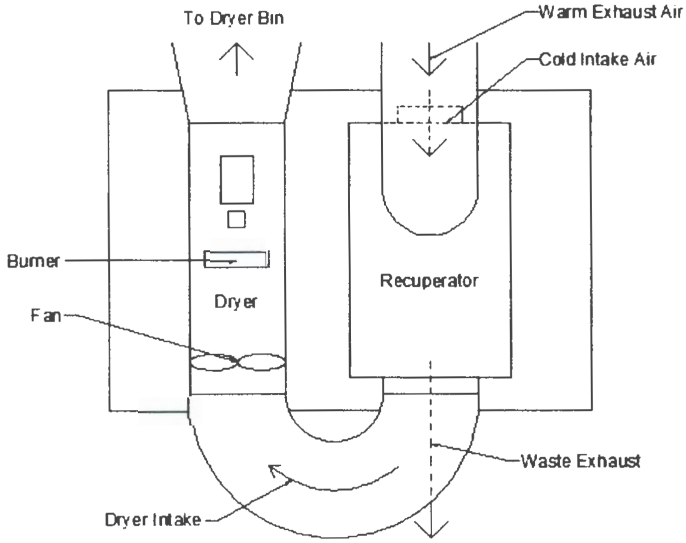

Figure 8. Concrete Pad Layout.

Calculations and Design Considerations

This project aims to recirculate and recuperate the heat from at least half of the exhaust air from the crop dryer. The Peerless dryer has an inside diameter of 22 ¼" with parts inside that restrict air flow. If this information is used as an estimated base line we get:

$$A = \frac{\pi(22.25")^2}{4} \times \frac{1}{2} \approx 194.41 \text{ sq in}$$

Rounding that number up to 200 sq in gives the project some extra capacity to account for internal restriction. The recuperator has to fit within the concrete pad next to the dryer so the width must be within two feet. Figure 9 shows an excel table used to calculate specific dimension of parts while maintaining a 200 sq in area for both the waste exhaust and cold air flows.

Table 1. Project Dimensions.

Area	200	sq in
Intake slots	5	
Exhaust Slots	6	
total slots	11	
alum width	0.0508	"
# alum dividers	10	
steel width	0.0747	"
height	24	"
Bolts	9	
Spacer Size	1.75	"
# of spacers	99	
length of pipe	14.4375	ft
inside width	19.758	"
outside width	19.9074	"
unbent width of top panel	23.9074	"

Other Considerations

Other design considerations include the positioning of the inlets and outlets. The dryer exhaust air inlet and the cold air intake of the recuperator must be located together on the end of the recuperator that faces the dryer bin for the most efficient ducting. The other end will have the recuperator output and waste exhaust outlet facing the intake of the dryer and ducting will connect the two. This pass-through design will allow for minimally restricted airflows. Temp measurements will be taken at both ends of the recuperator during testing.

Recuperator Design

Figure 10 shows a general overview of the design and the location of cross sections. Figures 11, 12, 13, 14 show detailed drawings of the individual components with dimensions.

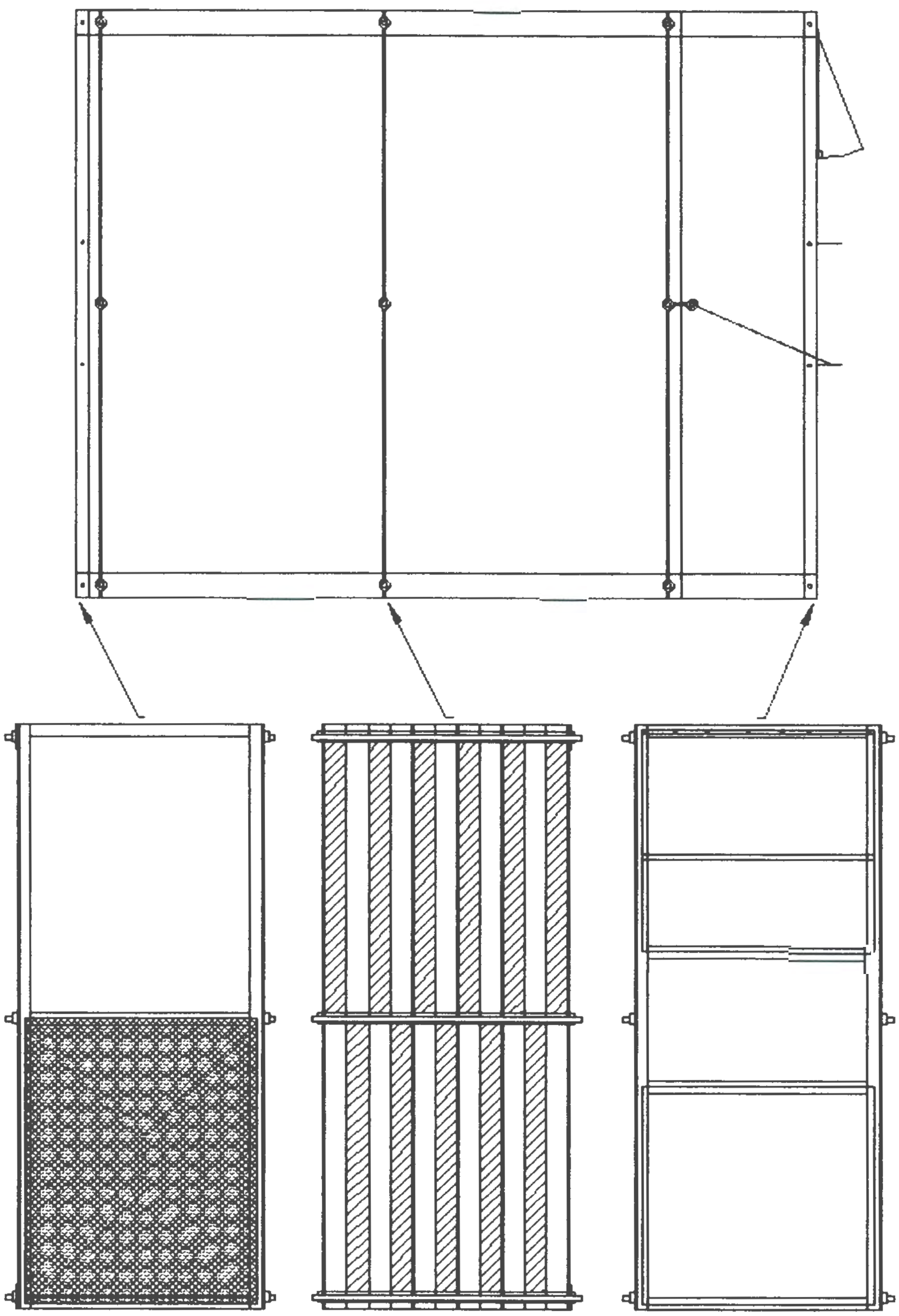

Figure 9. Design Overview.

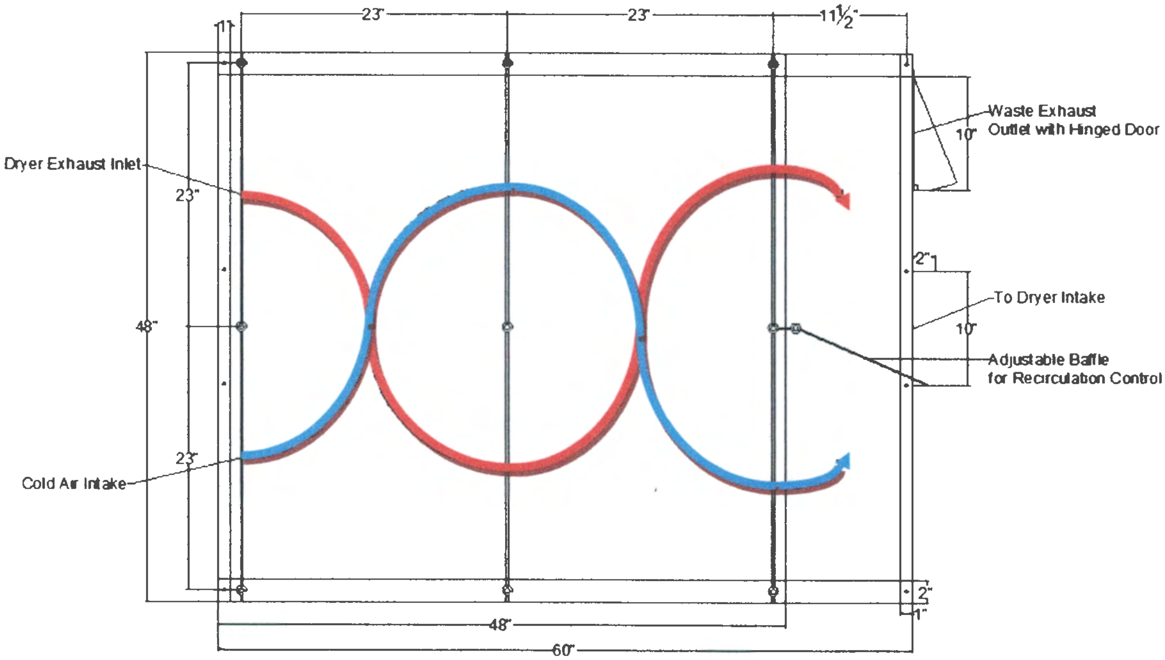

Figure 10. Side View.

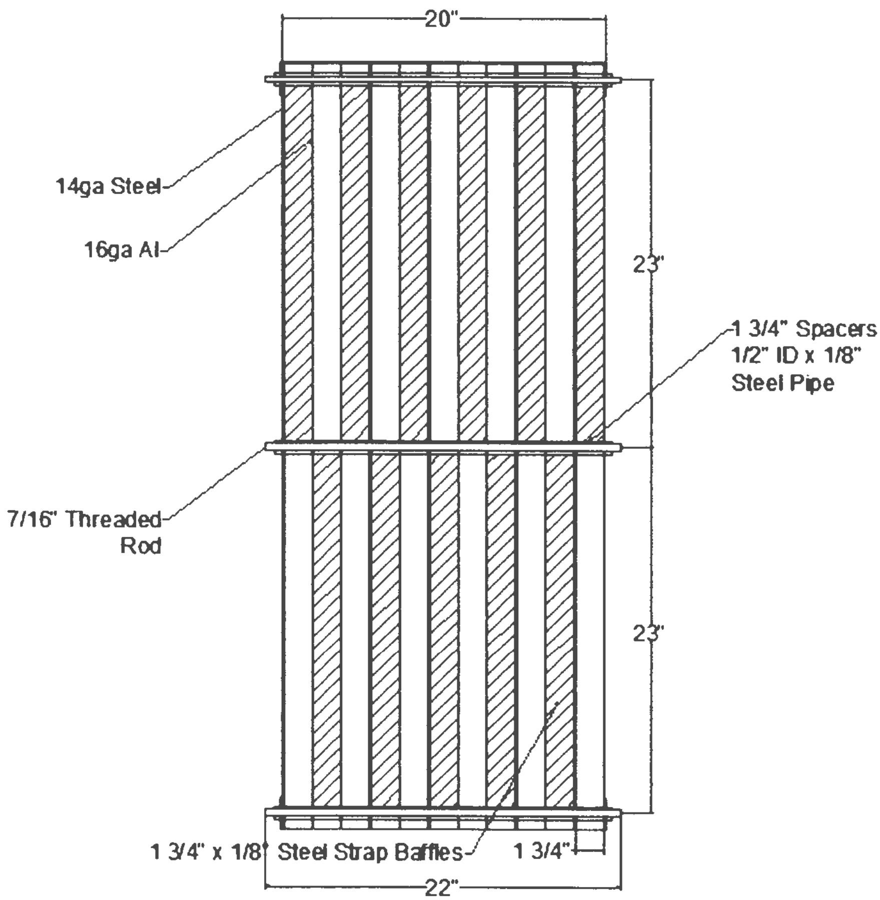

Figure 11. Interior Cross Section View.

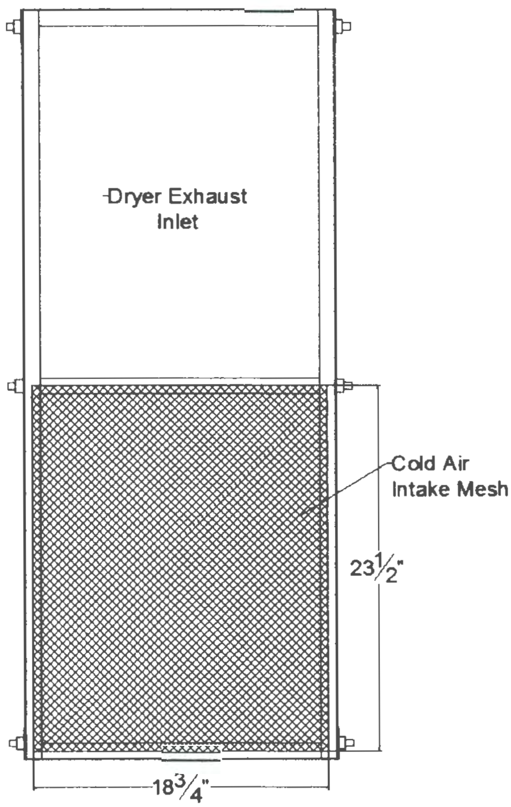

Figure 12. Intake Side View.

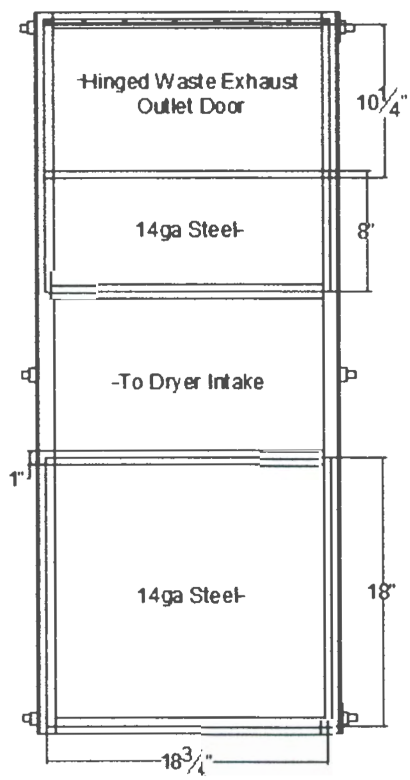

Figure 13. Output Side View.

Construction

This project uses sheets of steel and aluminum of nominal sizes to minimize shearing required. Sheets were stacked and clamped in place and drilled with ½" holes. After the spacers were cut and the baffles were welded, the sheets and baffles were sequentially stacked while the threaded rod held them in place as shown in Figure 15. Top and bottom panels were sheared and bent. The intake panels were be fabricated and assembled.

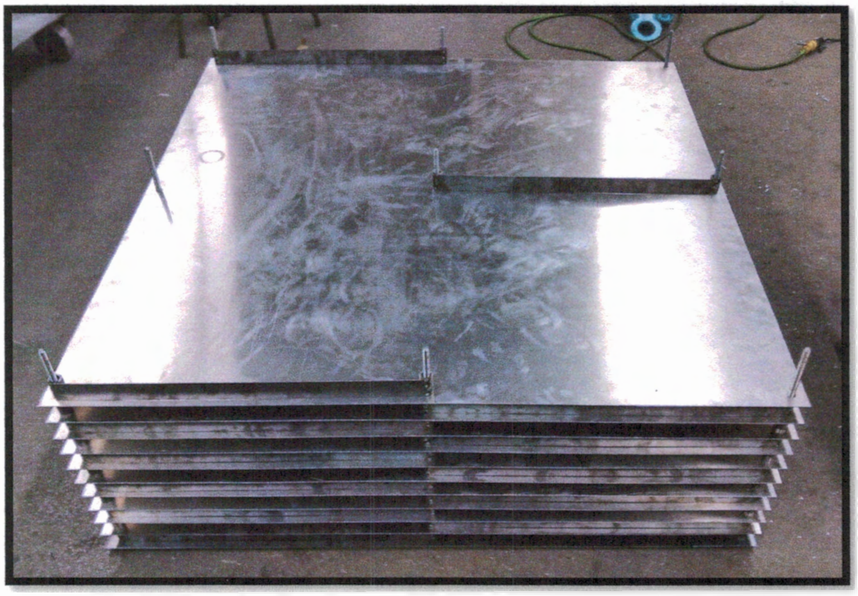

Figure 14. Construction of Recuperator Core.

Testing Procedure Design

The recuperator will be moved to the drying operation before this fall. It will be positioned on the concrete pad and ducting will be used to connect the recuperator into the system. Walnut season is from August to late October. Walnuts vary in moisture content throughout the season and early season nuts require significantly more drying. To account for this, the test will not be performed until mid season when the drying times are more typical.

Freshly processed wet nuts will be placed in the drying bin and the moisture content will be measured using an already existing moisture meter mounted inside. The dryer will be ignited and allowed to run until the walnuts reach an average moisture content of 8%. The first test will be performed without the recuperator and will act as a control.

The test will then be repeated with the recuperator. Walnuts from the same batch will be used to eliminate other variables. Two kinds of tests will be performed with multiple trials each. Figure 16 shows an example of a table to be used for testing.

Table 2. Example Test Table.

Recirculation Test					
	Beg MC %	End MC %	Drying Time	Intake Temp (°F)	Exhaust Temp (°F)
Test 1 (control)					
Test 2 (25% Recirculation)					
Test 3 (50% Recirculation)					
Test 4 (75% Recirculation)					
Test 5 (100% Recirculation)					

The first test will monitor several things. Exhaust and intake air temperature will be measured using probes placed inside the ducting of the drying bin. Fuel used could be measured precisely during the entire drying cycle using a meter on the fuel line. EKM Metering in Santa Cruz, CA offers a PGM.75 model gas meter that could work for this application. Drying time is defined as the amount of time the walnuts take to reach about 8% moisture content. Recirculation will be adjusted throughout the different trials. The second process will test recuperation with no recirculation. The process will monitor the temperature of dryer exhaust air entering the recuperator and the waste air leaving the recuperator to determine the amount of heat that is being effectively recuperated.

RESULTS

Scalability

This model has an estimated capacity of half of the output of one standard Peerless dryer. The recuperator has been designed to be scalable. This is accomplished by either using multiple units in parallel or by doubling the width with more plates.

Testability

The unit will be tested during the coming walnut season (Fall 2014). The exhaust gas temperature and humidity will be monitored throughout multiple drying cycles. The information will be used to calculate the optimum amount of recirculation in each phase of the drying cycle. The test will then be repeated and the amount of recirculation controlled to improve drying times and fuel efficiency compared a typical dryer setup.

Costs and Bill of Materials

Bill of Materials. The final list of materials purchased is shown below in Figure 17. The final materials cost is totaled at the bottom. The materials were supplied by Whitten Machine Co., Mid Valley Pipe & Supply INC, and C & J Fasteners. All suppliers are located in Tulare, CA.

Table 3. Bill of Materials.

Quanity	Description	Price/Unit	Price
5	16ga 4' x 8" Aluminum Sheets	$ 56.00	$ 280.00
2	16ga 4' x 10' Steel Sheets	$ 100.00	$ 200.00
2	21' x 1/2" ID Sch 80 Pipe	$ 23.00	$ 46.00
1	4' x 4' Mesh	$ 22.00	$ 22.00
1	1" x 20' Square Tubing	$ 34.00	$ 34.00
2	20' x 7/16" Treaded Rod		$ -
32	7/16" Nuts		$ -
32	7/16" Washers		$ -
		Project Total	$ 582.00

Costs and Comparison. The final bill of materials shows that the project was built under budget. Most of the costs came from the aluminum and steel sheets. This amount does not include labor for construction. Labor for installation and connection can be estimated at around 25 hrs and will be performed as part of the test plan.

RECOMMENDATIONS

Cost Reduction. In order to attempt to reduce the expenses, it is recommended that lighter materials be used in construction if it can be shown that they would have adequate structural rigidity. The largest costs were the aluminum and steel sheeting and any reduction in thickness of these sheets would significantly reduce the price and weight of the entire project as well as a possible increase in heat transfer.

Adaptability. The project was designed to be very adaptable to many different dryer set ups and layouts. It has a modular design that can be connected through ducting to many different dryers and bins designs. Multiple units could be run in series to extract more heat or units could run in parallel to increase recirculation capacity. This project could be scaled up and used in even a large-scale system.

Automation. With the results of this test, an optimum pattern of recirculation control can be realized. Recirculation will be controlled manually for the purposes of this project. This process could be automated with a PLC and an actuator which would monitor and control recirculation continuously.

REFERENCES

Eclipse Manufacturing, 2014. Cross Flow Recuperators. http://www.eclipsenet.com/products/cross_flow/

Kalfrisca Energy Recovery Equipment Manufacturing, 2014. Concepts of operation. http://www.kalfrisa.com/recuperaciondecalor.aspx

Peerless Manufacturing, 2014. Dryer Models. http://www.peerlessmfg.cc/dryers1.htm

UC Davis, April 2009. Walnut Dehydrator Workshop. Personally Attended

Appendix A:

Senior Project Contract

California Polytechnic State University	February 11, 2014
BioResource and Agricultural Engineering Department	Ribeiro, Ross J
ASM Senior Project Contract	004772556 ASM

Project Title

Analysis of crop dryer recirculation and heat recuperation

Background Information

Walnut dehydrators use propane and natural gas burners to heat air enough to dry walnuts. A large amount of residual heat is wasted in the exhaust air from the dryers. This project will analyze the feasibility of utilizing that wasted heat using recirculation and a heat exchanger. The regulators on the burners would use less fuel and this could result in a significant reduction in expense.

Statement of Work

This project will require data collection on the dryer to be tested and the efficiency of recirculation systems currently in use. Heat exchangers designs will also be researched. Different design options will be discussed. A proof of concept model will be constructed and a testing procedure will designed.

How Project Meets Requirements for the ASM Major

ASM Project Requirements - The ASM senior project must include a problem solving experience that incorporates the application of technology and the organizational skills of business and management, and quantitative, analytical problem solving.

Application of agricultural technology	The project is specifically analyzing the application of technology to the walnut processing industry.
Application of business and/or management skills	This project will require the use of business skills to economically analyze the application of a new technology.
Quantitative, analytical problem solving	This project is a proposed solution to an economic problem. Significant qualities will be measured to determine the effectiveness of the proposed solution and to analyze the economic benefits of the results.

List of Tasks and Time Estimate

TASK	Hours
Research on local commercial burning restrictions	10
Research heat exchangers on the market	20
Determine burner air flow rates	5
Design model	25
Construct model	70
Construct test plan	20
TOTAL	160

Financial Responsibility

Preliminary estimate of project costs: $ 1000

Finances approved by (signature of Project Sponsor): NA

Final Report Due: Spring 2014	**Number of Copies**: 2

Approval Signatures **Date**

		Date
Student:		
Project Supervisor:		
Department Head:		