DEVELOPMENT OF A SMALL-SCALE MEAT DRYER WITH AUTOMATED DUAL HEATING SYTEM

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Abstract - *A study aimed to develop a small-scale meat dryer with automated dual heating system was conducted to provide households and small-scale entrepreneurs with a low-cost dryer to improve the quality of dried meat in Oromia Region, Ethiopia. The main components of the dryer were the solar collector with 5cm thick rock heat storage, drying cabinet, 1kw electric heater, 0.3W 12V DC suction fan, thermocouple temperature sensor and controller. It was designed to operate on solar energy and electric heating systems at the same time during the day and on electric heating system at night. This was done to maintain an average operating temperature of 65°Cfor continuous operation. Results of the tests revealed that the dryer can dry5kg of meat in 24hours. This shortens the drying time of meat from 4 to 5 days when ordinary sun drying is used. The dryer produced high quality and clean dried meat compared to ordinary sun drying which expose the meat to dusts and other contaminants.*

Key Words: solar collector, rock heat storage, thermocouple temperature sensor, temperature controller, automated dual heating system

1.INTRODUCTION

Drying is one of the ways to preserve meat.Research showed that oven-drying and sun-drying increased the dry matter and protein contents of the dried meat compared to the fresh meat [1]. In Ethiopia, the absence of affordable dryer for small-scale operation is one of the problems in the area. Drying meat by ordinary sun drying will take4 to 5 days to occur [2]. This is done by hanging the meat strip on wooded sticks, wire or plastic rope in the open area. This method also exposes the meat to various contaminants such as dusts, flies and other elements. The resulting product is therefore of low quality and often contaminated. Presently, there are commercial dryers that are available for meat. However, these equipment are expensive and need to be imported. They are also beyond the financial capacity of poor households and small entrepreneurs in developing countries like Ethiopia.Ethiopia's live animal exports are estimated at 2,323,500 [3]. Furthermore, the country hadthe highest livestock population in Africa at the end of 20th century [4]. On the other hand, Ethiopia has a yearly average daily radiation reaching the ground of about 5.26 kWh/m^2 [5]. In Afar region of the eastern Ethiopia, the yearly average daily radiation reaches 6.10 kWh/m^2 [6].In spite of this abundance of solar energy, meat drying using ordinary sun drying is still prevalent in the country. This research was conducted to develop a meat dryer with automated dual heating system suitable for small-scale operation using locally available materials in the area. The technology is expected to address the needs of small entrepreneurs and households to produce high quality dried meat and free from contamination.

2. MATERIALS & METHODS

2.1 Design Concept

The recommended temperature for meat drying ranges from 60 to 65°C [7] or from 63 to 68°C [8]. In this study, the prototype meat dryer was designed to operate at an average temperature of 65°C continuously using solar and electric heating systems. The dryer used solar and electric heating systems at daytime, and electric heating system alone at night. It was intended for household use and small-scale drying operation.

The dryer used solar collector with rock heat storage, and electric heater. A thermocouple temperature sensor and controller were used to turn the electric heater on and off to maintain the desired mean operating temperature of 65°C. To increase the drying rate and effect a more uniform temperature, a suction fan was used. Figure 1 shows the simplified block diagram of the dryer's heat control system. The main components of the prototype meat dryer were the solar heat collector with rock heat storage, electric heater, temperature sensor and controller, suction fan and drying cabinet (Figure 2).

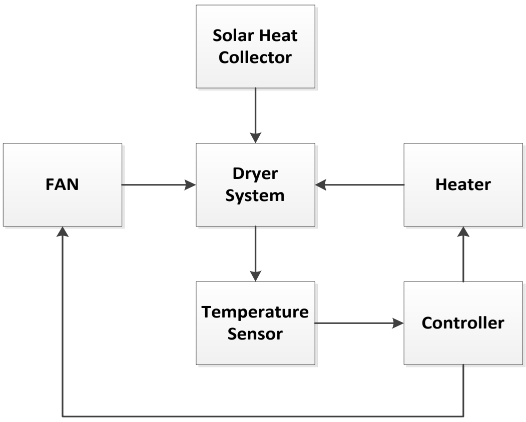

Fig -1: Simplified block diagram of the meat dryer heat control system

2.2 Solar heat collector

The solar heat collector (thickness=15cm, width=60, length=120cm) was made of 12mm thick plywood, 3mm thick glass and an ordinary lumber. The solar collector had air intake holes at the lower end of the box, a 3mm thick glass cover, and 5cm thick crashed rock heat storage. The rocks were sprayed with black paints to enhance absorption of solar radiation. The other end of the solar collector was attached to the drying cabinet.

2.3 Drying cabinet

The drying cabinet (thickness=30cm, width=60cm, height=100cm) was made of 12mm thick ordinary plywood while the frame was made of 2.5x5cm lumber. It was designed to hold at least 5kg of meat per batch. The front side was covered with a 3mm thick glass to increase the area of solar collector, and to enable direct viewing of the meat inside the cabinet. The meat strips were placed in the cabinet by hanging them using a plastic rope. The top portion of the drying cabinet was perforated to allow the free flow of drying air through natural convection when the suction fan was not in operation.

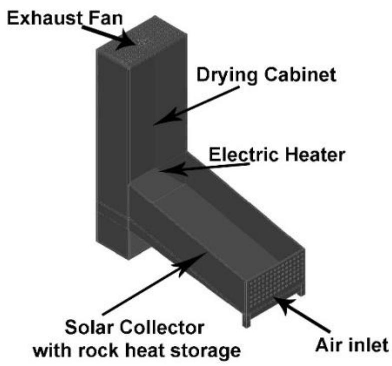

Fig -2: Main components of the prototype meat dryer

2.4 Capacity of electric heater

The electric heater was used to provide additional source of heat when solar energy wasin adequate to maintain the drying temperature of 65oC. The heater also compensates for the heat losses from the drying cabinet. Heat conduction loss from the cabinet was estimated using the equation [9]:

$$q = kA\frac{T1-T2}{L} \quad \text{-------------} \quad (1)$$

where:

k = thermal conductivity of the materials,

A = surface area,

L = length of the material which the temperature conduct

T1 - T2 = air temperature difference outside and inside the dryer.

The electric heater was designed to provide adequate energy source when the air temperature in the area drops to a minimum of 10oC during cold months. Based on this minimum ambient air temperature, the maximum estimated heat loss from the drying cabinet was about 250WHr. Its power consumption is about 800 watts when the power factor is 0.80. The maximum amperage of the electric heating system is 4.54A at 220V. Thus a 1KWelectric heater was used as an additional source of energy for the dryer.

2.5 Temperature sensor and controller

A thermocouple temperature sensor and controller were used to maintain the operating temperature of 65oC of the dryer. The sensor monitors the temperature and automatically sends a signal to the controller to turn-on or off the heater when the drying temperature falls above or below 65oC. The sensor was capable of sensing temperature from 0 to 300oC.

2.6 Suction fan

A 12V, 0.3 watt brushless DC suction fan was installed at the top of the drying cabinet to effect a more uniform and fast drying rate. The fan rotates at a constant speed of 2000 rpm and runs continuously for the entire drying period. The fan increased the volume of air that passes through the solar collector then to the meat strips thereby enhancing the drying rate.

2.7 Performance Test

The prototype dryer was tested in Adama City, Ethiopia with geographic coordinates of 8.55N and 39.28E and mean elevation of 1622 meters above mean sea level. December is the coldest month in the area with mean minimum temperature of 10.5oC, while April is the hottest month with mean maximum temperature of is 30.3oC.The area is windy with annual average wind speed of 59km/day. Solar radiation varies from 19 to

22.4MJ/m2/day, while relative humidity varies from 53 to 70% with annual mean of 59%.

The prototype meat dryer was tested using beef. The beef was first thinly sliced forming a strip after which it was soak in a salt solution containing vinegar and some seasonings to improve its flavour. Then the meat strips were hanged on plastic ropes in the drying cabinet (Figure 3).The test was conducted from 9AM to 5PM. The ambient air temperature was monitored during the entire drying process using a mercury thermometer.

Fig -3: The prototype dryer loaded with meat strips

3. RESULTS AND DISCUSSION

3.1 Operating temperature without the electric heater and suction fan

Chart 1 shows the temperature in the drying cabinet when only the solar collector was used. The dryer reached a maximum temperature of 70°C.Considering the minimum meat drying temperature of 60°C, the solar collector only provided about 3 hours of sufficient energy for drying during the test. The sudden dropped in operating temperature in late afternoon was attributed to the strong wind. An electric heater is therefore needed to maintain the recommended average drying temperature of 65°C.

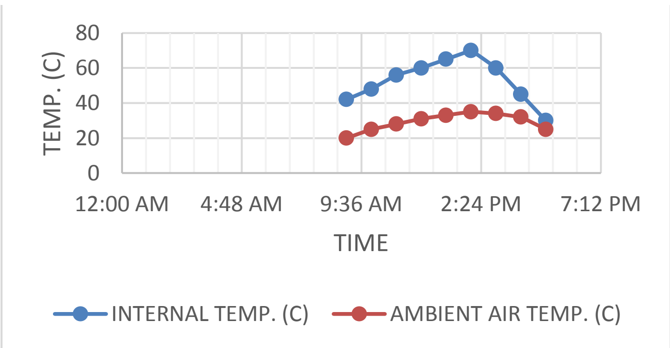

Chart -1: Temperature in the dryer and ambient air during test

3.2 Temperature profile in the dryer with and without a suction fan

The temperature profile in the dryer was also investigated with and without a suction fan, and the solar collector alone as the source of heat. This was done in late afternoon when the ambient air temperature was about 35°C. The temperatures at different distances from the suction fan were measured with a thermocouple. With a suction fan off, the temperature in the dryer varied from 53 to 59°C at 20cm and 100cm away from the suction fan, respectively. When the suction fan was turned on, the temperature dropped to 40 and 47°C at 20cm and 100cm away from the suction fan, respectively (Chart 2). This temperature drop can be attributed to increased volume of air passing through the dryer when the suction fan was turned on. The dryer cannot develop the required drying temperature when it only relies on solar collector with the suction fan in operation.

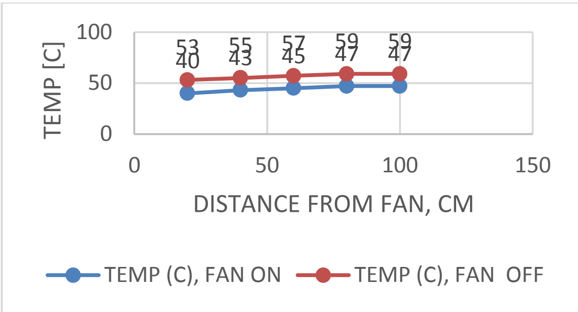

Chart -2: . Internal temperature of the dryer as a function of distance from the suction fan

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3.3 Temperature profile in the dryer without the solar collector

The temperature profile in the drying cabinet was also determined without the solar collector at different distances from the heater. This was done before sunrise when the ambient air temperature was at minimum (25°C). The only source of heat was the 1kw electric heater. The dryer was preheated for about an hour before the measurements were made. Results showed that the temperature varied from 57 to 65°C at 100cm and 20cm from the heater, respectively. On the average, the temperature decreased by 0.1°C per cm increase in distance from the heater (Chart 3).

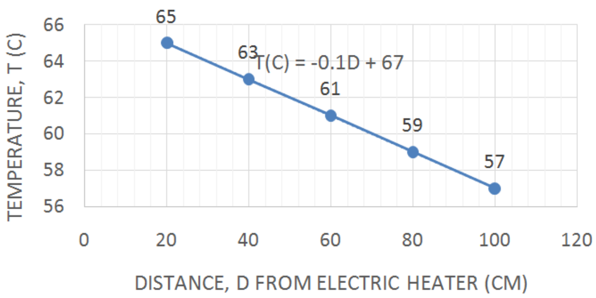

Chart -3: Internal temperature, T(°C) as a function of distance, D(cm) from electric heater

3.4 Meat drying time with solar and electric heater as heat sources

The dryer was tested using 5kg meat with both solar and electric heater as sources of heat. Results showed that the meat strips were dried for a period of 24 hours at an average operating temperature of 65°C (Figure 4).

Fig -4: Dried meat produced from the dryer after 24 hours

4. CONCLUSIONS

Based on the results of the tests, the dryer performed as designed and can dry at 5kg of meat a day when the drying temperature is maintained at 65°C. The dryer consumes less energy because it uses both solar and electric energy during drying operation. It also produced high quality dried meat because of the protection it offers during drying operation. The dryer can also be used regardless of the weather conditions because it utilizes both solar and electric power as sources of energy for heating.

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BIOGRAPHIES

Rogelio B. Paguntalan is presently a Professor of Agricultural Engineering in Adama Science and Technology University, Adama City, Federal Democratic Republic of Ethiopia. He was born in Moises Padilla, Negros Occidental, and Philippines on March 19, 1951. He obtained his BS degree in Agricultural Engineering from the University of Southern Mindanao in 1976, MS degree in Agricultural Engineering (Farm Machinery) from the University of the Philippines at Los Banos in 1984, and a PhD degree in Agricultural Engineering (Soil & Water Management) from Central Luzon State University, Philippines in 2003. Before coming to Ethiopia, he served as an Assistant Professor and Associate Professor of Agricultural Engineering in Central Mindanao University from June 1993 until his retirement on May 2014. He also held various administrative positions in the same university as a Head of Agricultural Engineering Department, Associate Dean and finally, Dean of the College of Engineering. He is a Registered Professional Agricultural Engineer in the Philippines, and had worked in various private companies and government institutions in the Philippines and abroad. From 1987 to 1992, he worked at the Animal Research and Development Center, Sakaka, Al Jouf, underthe Ministry of Agriculture and Water, Kingdom of Saudi Arabia. As a practicing agricultural engineer, he also served as a consultant to some of International NGOs, Agricultural Companies and Local Government Units in the Philippines.

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