Simulated Air Flow Rate Effects on Drying Times and Costs for Conventional and Recirculating Peanut Drying Facilities[1]

L. Chai * and J.H. Young[2]

ABSTRACT

In conventional nonrecirculating peanut drying systems, an air flow rate of 10 $m^3/min\text{-}m^3$ is recommended. Drying systems utilizing air recirculation need not consider the inefficiency associated with unsaturated air exiting the system, since the extra drying capacity of the air will eventually be utilized. As a result, the air flow rate recommendation for recirculation type drying systems needs to be reexamined. In this study, two computer models were modified to simulate the peanut drying process in a solar-assisted partial air recirculation drying system and a conventional drying system, respectively. The weather data from the 1992 drying season at Lewiston, NC and the parameters of both facilities were used as the input data for the models. Air flow rates of 5, 7.5, 10, 12.5, 15, 17.5, 20, and 22.5 $m^3/min\text{-}m^3$ were examined. The simulation results showed that the effect of air flow rate on drying times and costs in a solar-assisted partial air recirculation peanut drying facility was significant. When the air flow rate was increased, the seasonal drying capacity, the electrical and fuel consumption, and total or specific drying cost increased as well. On the other hand, drying time for each wagon decreased and total energy consumption remained relatively constant.

Key Words: Peanut, drying facility, air flow rate, drying cost, drying time, conventional, recirculation.

Conventional peanut drying systems were designed for practicality, convenience, and uniformity in drying with little emphasis on the energy efficiency. The combination of high air flow rates and a single pass of the air

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[2] Grad. student and Prof., Biol. and Agric. Eng. Dept., North Carolina State Univ., Raleigh, NC 27695-7625.

* Corresponding author.

through the peanuts resulted in inefficient drying because the air exiting from the top of the wagon often still had drying potential. Cundiff *et al.* (3) studied the influence of air flow rates on drying time, electrical energy consumption, and fuel consumption in the conventional systems. The results showed increasing the air flow rate beyond 10 m^3/min-m^3 did not have any economic advantage. Young (5) compared the energy efficiency of recirculating type dryers and conventional single-pass dryers using small experimental units (1.22 m^2 with a depth of 1.37 m) each having their own controls for temperature and relative humidity. The average results from a 3-yr study were energy savings of 26%, drying time reduction of 15%, and slightly (but statistically significant) higher market values for the peanuts dried in the recirculating dryers as compared to those dried in conventional dryers. A four-wagon peanut drying facility using partial air recirculation and a solar attic was designed, constructed, and tested by Young *et al.* (7). Total energy consumption in the facility was approximately 40% less than in conventional peanut drying systems.

The objectives of this study were to use model simulation techniques to calculate the effect of air flow rate in recirculation and conventional systems on the consumption and cost of both fuel and electricity, total cost, drying time in each wagon, and seasonal drying capacity (number of wagons dried per season).

Materials and Methods

Assumptions. In order to simplify the problem and make valid comparisons, the following assumptions were made in the simulation models:

1. There was no air leakage in the wagons of the recirculating system or in the wagons/plenum of the conventional system.
2. The initial wet basis moisture contents of kernels and hulls in each wagon were 25 and 18%, respectively. Only four wagons were dried at any time and were started simultaneously. The peanuts were considered dry when the moisture content of kernels in the top layer of each wagon reached 10%. Once the peanuts in all four wagons were dry, they were simultaneously replaced by four wagons containing wet peanuts.
3. The drying season was 1 Oct. 1992, at 1:00 AM until 12:00 PM on 31 Oct.

Description of Drying Facilities. A drying facility utilizing the plenum/wagon method, partial air recirculation, and the use of solar energy was designed and constructed at the Peanut Belt Research Station at Lewiston, NC in 1987. Figure 1 is a schematic drawing of the system consisting of a main drying room capable of housing up to four drying wagons and an attic in which solar energy is collected.

Each wagon connects to its own fan which supplies sufficient air flow at a rate independent of how many wagons are in the drying room. The exhaust air from the wagons mixes in the main room of the drying facility and unsaturated air may be recirculated.

If the relative humidity within the facility becomes higher than desired for proper drying of the peanuts, then inlet shutters open and the main duct fans draw in fresh air from outside. An equal volume of humid air is exhausted through gravity vents in the front of the facility.

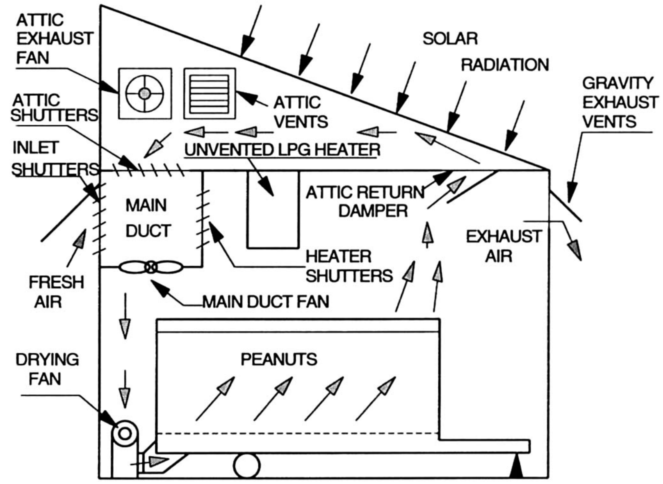

Fig. 1. Schematic drawing of the partial air recirculation drying facility with solar attic.

Temperature within the structure is maintained by either pulling air through the solar attic or by adding heat with supplemental liquid propane gas (LPG) heaters. If the temperature in the main drying room is below the setpoint (29 C in this study) and the attic temperature is high enough to provide energy (above 33 C in this study), then the attic return damper and the attic shutters open so that air passes up through the attic return damper near the front of the main drying room, through the attic, down through the attic shutters and main duct in the rear, through the main duct fans, and back into the drying room. If the solar energy collection of the attic is insufficient to maintain the setpoint temperature in the main drying room (26.5 C), then the supplemental LPG heaters are turned on and heater shutters open to pull air from around the heaters into the main duct for distribution into the main room. If the attic temperature is below a setting of 30.5 C, then all heating is from supplemental heaters and the dampers and shutters to the attic are closed to prevent energy loss.

The drying facility design described above utilizes only one set of controls for maintaining the desired conditions in the main room. This facility does not provide any significant storage for solar energy but does utilize the energy collected by the building attic to reduce the quantity of LPG required.

Figure 2 is a schematic drawing of the conventional drying system. All four wagons connect to a main plenum with the duct fan fixed to one end of the plenum. The fan draws in fresh air from outside and pushes it through the peanuts from the bottom to the top of the wagons during the drying process. The air exhausts from the wagon to the outside. Plenum baffles are used to equalize air flow rate to the four wagons. If the ambient temperature is below the setpoint (24 C in this study) and the ambient relative humidity is above the setpoint (65% in this study), then the supplemental LPG heater is turned on to raise the temperature of the air drawn into the main plenum by 6 C.

Model Description. The computer simulation model, DRYSIM2G, for the recirculating system was modified based on the model DRYSIM written by Cain (1).

The flow chart describing DRYSIM2G is shown in Fig. 3. DRYSIM2G used a numerical thin-layer peanut drying

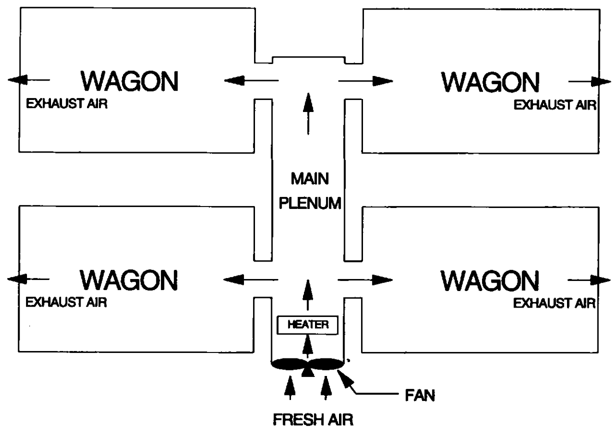

Fig. 2. Schematic drawing of the conventional drying facility.

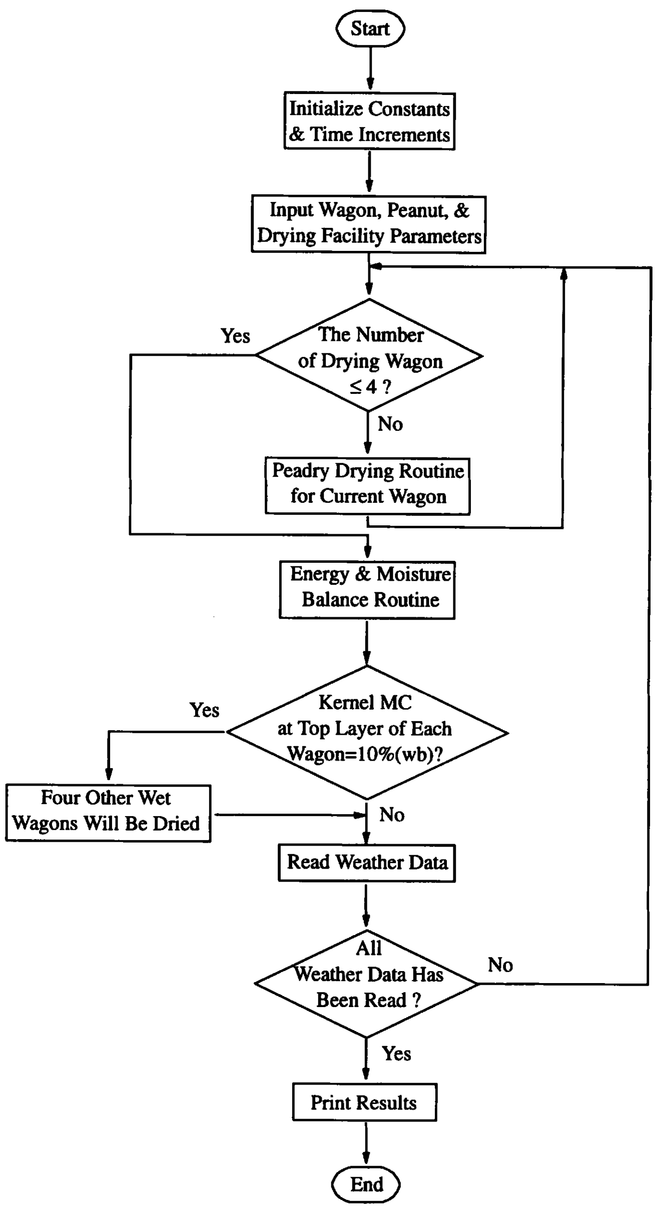

Fig. 3. General flow chart of DRYSIM2G.

model, PEADRY8, developed by Colson and Young (2), that treated the pod as two components (kernels and hulls) with moisture movement proportional to a combination of moisture content gradients (liquid diffusion) and vapor pressure gradients (vapor diffusion). Use of PEADRY8 for simulating bulk drying of peanuts was described by Parti and Young (4). The total depth of the peanuts was divided into 10 layers. The model used heat and mass balances to determine the changes in air temperature and moisture for each time step. For the simulation, moisture contents at each layer were calculated at 10-sec increments. An exponential thin-layer drying equation was used to calculate the moisture content of each layer at the end of each time increment. The energy and moisture balance relationships for the total drying system were developed on the principle of conservation. The 1-sec time step for the balances on the total system was small enough to minimize numerical errors.

A flow chart describing the computer simulation model, DRYSIMCO, for the conventional drying system is shown in Fig. 4. DRYSIMCO is a modification of the model PEADRY8. The energy and moisture balances of the conventional system does not have to be considered in the model because the air exits from the top of the drying wagon.

The input data for both models was composed of five parts: (a) weather data (dry-bulb and wet-bulb tempera-

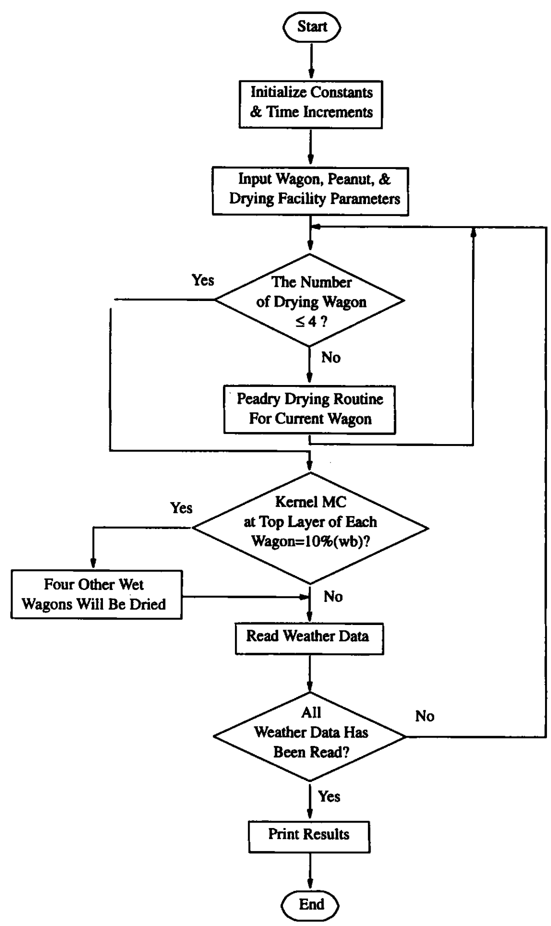

Fig. 4. General flow chart of DRYSIMCO.

ture, relative humidity, and total solar radiation) that was taken every 5 min at Lewiston, NC during the 1992 drying season (1-31 Oct.); (b) system parameters, such as fan capacity and efficiency, building dimensions, and properties of structure materials, etc.; (c) control logic parameters, they were temperature and relative humidity limits at which certain devices were turned on or off; (d) initial and final moisture contents of the kernels and initial moisture content of hulls; and (e) air flow rate.

The output data included the drying time for each wagon, number of wagons that were dried in the season, fuel and electricity consumption, fuel and electricity costs, seasonal total cost, and specific cost (cost per wagon dried).

Air flow rates of 5, 7.5, 10, 12.5, 15, 17.5, 20, and 22.5 $m^3/min\text{-}m^3$ were used for both drying systems in this study. The two models were run with the above air flow rates separately.

Results and Discussion

Drying Time and Seasonal Drying Capacity. From the peanut farmers' point of view, shorter drying times are desirable because they allow more peanuts to be dried during a limited drying season. Drying time was calculated for peanuts dried with air flow rates ranging from 5 to 22.5 $m^3/min\text{-}m^3$. As air flow rate increased from 10 to 17.5 $m^3/min\text{-}m^3$, average drying time of each wagon decreased 22.53% (from 88 to 68.17 hr) for the conventional system; and 20.75% (from 77.98 to 61.8 hr) for the recirculating system (Fig. 5). The drying capacity of the conventional system increased 25% (eight more wagons are dried) and that of the recirculation system increased 33% (12 more wagons are dried) (Fig. 6). In the actual conventional drying process, an air flow rate of 10 $m^3/min\text{-}m^3$ was recommended in North Carolina by Young *et al.* (6).

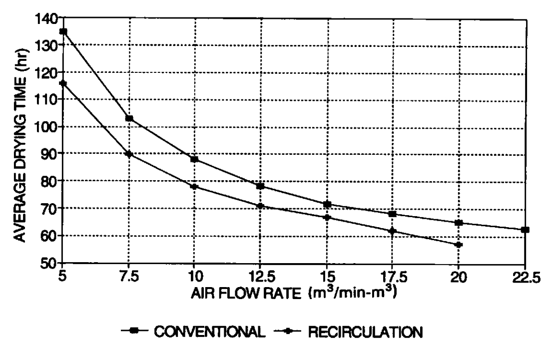

Fig. 5. Average drying time vs. air flow rate.

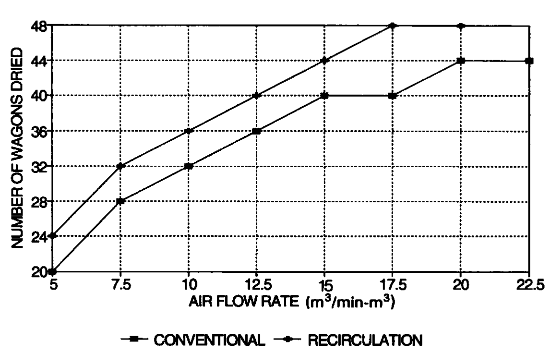

Fig. 6. Number of wagons dried vs. air flow rate.

Comparing the recirculating and conventional systems at 10 $m^3/min\text{-}m^3$, four more wagons were dried and drying time decreased 11.39% (10.02 hr) by using the recirculating system. Figure 5 also shows that the drying time in the recirculating system was shorter than that in the conventional system for all air flow rates tested.

In the conventional system at lower air flow rates, the air becomes saturated with moisture before it exits the top of the wagon. The drying rate is limited both by the thermal and moisture characteristics of the air and by internal moisture migration within the peanut pod. At high air flow rates, the internal moisture migration is the primary limitation on drying. Once air flow rate has been increased to the point where the air can no longer become saturated, the effect of continuing to increase air flow rate is insignificant. However, in the recirculating system, since the air exiting the top of the wagon is recirculated, the drying potential of the air is more fully utilized. As a result, both high energy efficiency and high peanut drying rate within a limited seasonal period are associated with the recirculating system.

In addition, Fig. 6 indicates no more wagons were dried if the air flow rate was higher than 17.5 $m^3/min\text{-}m^3$ in the recirculating system. We can consider this value as an upper bound of the air flow rate. On the other hand, it is unnecessary to consider any air flow rate lower than 10 $m^3/min\text{-}m^3$ which is the recommended value being used in conventional systems. Therefore, all the comparisons in this study were made within the range of 10 to 17.5 $m^3/min\text{-}m^3$ rather than 5 to 22.5 $m^3/min\text{-}m^3$.

Electrical Consumption and Electricity Cost. Figure 7 shows that the electrical consumption of both conventional and recirculating systems increased when air flow rate increased from 5 to 22.5 $m^3/min\text{-}m^3$. The electrical consumption for air flow rate from 10 to 17.5 $m^3/min\text{-}m^3$ increased 330.34% (8843.39 kwh) and 280.46% (9818.45 kwh) for the conventional and recirculating systems, respectively. More power was required by the drying fans to provide more pressure to push the air through the peanuts in the wagon as the air flow rate became higher. For an air flow rate of 10 $m^3/min\text{-}m^3$, the electrical consumption was 30.77% (823.84 kwh) higher in the recirculating system than that in the conventional

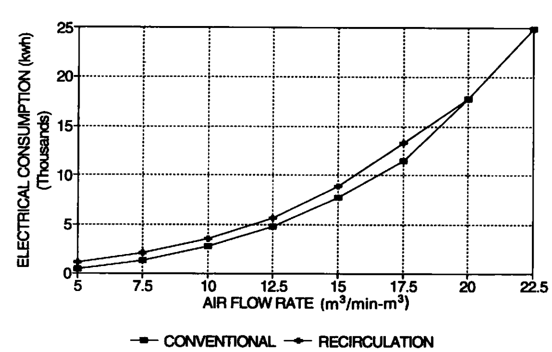

Fig. 7. Electrical consumption vs. air flow rate.

system.

There are two main duct fans in the recirculating system. Their function is to draw in fresh air at the appropriate time to maintain the relative humidity within the facility. The extra electrical consumption of these fans is the difference between the two curves in Fig. 7.

Since the electricity cost is proportional to electrical consumption (the unit electricity cost is \$0.08/kwh), it is possible to get the relationship between electricity cost and air flow rate in the two systems from Fig. 7. An extra electricity cost of \$707.48 in the conventional system and \$785.48 in the recirculating system was required when the air flow rate increased from 10 to 17.5 m^3/min-m^3. Also, the cost was \$65.91 more for the recirculating system than for the conventional system when air flow rate was equal to 10 m^3/min-m^3.

Fuel Consumption and Cost. Fuel consumption, shown in Fig. 8, increased as air flow rate increased in the conventional system. The higher the amount of air passing through the main plenum within a unit of time, the more heat was needed to raise the air temperature before it entered the wagons. The fuel consumption increased by 75% (3966.46 L of LP gas) as air flow rate increased from 10 to 17.5 m^3/min-m^3. The situation was quite different in the recirculating system. The fuel consumption curve was convex and the maximum value (3879.17 L) was achieved when air flow rate was about 12.5 m^3/min-m^3. This is because the unsaturated air exiting from the top of the wagon can be recirculated through the system if the relative humidity in the main room is below the setpoint (72% in this study). In addition, the dry-bulb temperature of the air as it passed through the attic was increased by solar radiation (if the attic temperature during the day time is above 33 C and the room temperature is below 29.0 C). Thus, compared with the conventional system, the heat energy required in the recirculating system from the supplemental heaters (or fuel consumption) is less at any given air flow rate.

Figure 8 indicates that fuel consumption in the recirculating system also increased with air flow rate at low air flow rates but reached a peak value at approximately 12.5 m^3/min-m^3. At higher air flow rates, the drying efficiency for each pass of the air was less, and greater energy input from larger fans replaced some energy required from the LPG heaters. In the simulation tests, the desired temperature for proper drying was exceeded at air flow rates above 17.5 m^3/min-m^3. Heat energy from the fans was a factor to be considered for selecting the air flow rate.

Figure 8 also shows how the fuel cost changes as the air flow rate changed based on the unit fuel price of \$0.198/L. At the air flow rate of 10 m^3/min-m^3, the fuel cost was 30.73% (\$322) less in the recirculating system than in the conventional system.

Total and Specific Cost. As Fig. 9 shows, the total seasonal drying cost (sum of electrical and fuel costs) in both the conventional and recirculating systems increased with air flow rates. The total cost was always lower in the recirculating system than in the conventional system in the range of air flow rates from 10 m^3/min-m^3 to 17.5 m^3/min-m^3. The total cost increased 72.55% (\$729.77) in the recirculating system and 118.32% (\$1493.42) in the conventional system in the air flow rate range mentioned above. Compared with the conventional system, the total cost saving in the recirculating system increased from 20.29% (\$256.1) to 37.00% (\$1019.65) as the air flow rate changed from 10 to 17.5 m^3/min-m^3.

Specific cost was defined as the total drying cost per wagon dried. It equals the total seasonal drying cost divided by the number of wagons that were dried during the season. Figure 10 compares the specific costs of the conventional and recirculating systems. In the recirculating system, the specific cost was always lower than that in the conventional system. The reason was the total cost was less and the number of wagons dried was more in the recirculating system than the conventional system. The specific cost increased 29.42% (\$8.22/wagon) in the re-

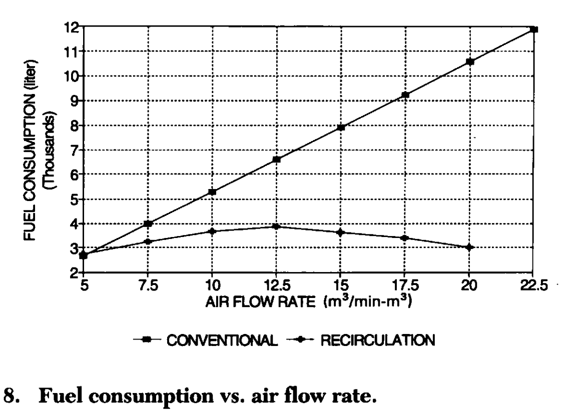

Fig. 8. Fuel consumption vs. air flow rate.

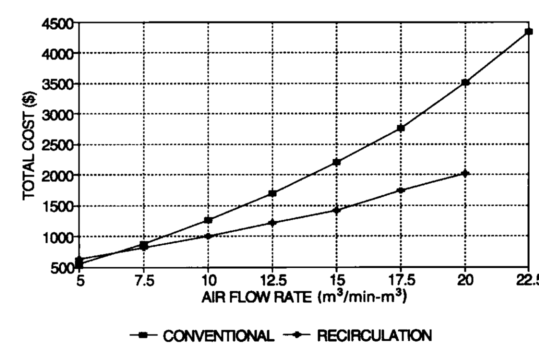

Fig. 9. Total cost vs. air flow rate, based on electrical cost of \$0.08/kwh and fuel cost of \$0.198/L.

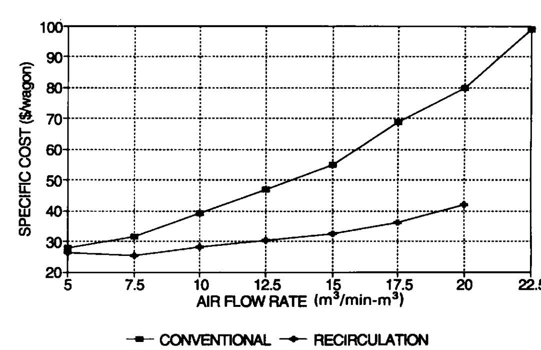

Fig. 10. Specific cost vs. air flow rate, based on electrical cost of \$0.08/kwh and fuel cost of \$0.198/L.

circulating system and 74.67% ($29.45) in the conventional system as air flow rate increased from 10 to 17.5 m^3/min-m^3. In addition, the specific cost saving at an air flow rate of 10 m^3/min-m^3 was 29.12% ($11.50/wagon) compared with the conventional system.

The specific cost of $36.16/wagon at an air flow rate of 17.5 m^3/min-m^3 in the recirculating system was less than the specific cost, $39.44/wagon, at an air flow rate of 10 m^3/min-m^3 in the conventional system (Fig. 10). If we only consider the specific cost, even if the air flow rate is increased to 17.5 m^3/min-m^3, the recirculating system still has an economic advantage for operating costs.

Energy Consumption. Figure 11 shows electrical energy consumption per unit of water removed by the drying system with different air flow rates. The consumption in both systems increased with air flow rate. The electrical energy saving by using the recirculating system compared to the conventional system changed from -16.24 (-66.29 kJ/kg_{H2O}) to 3.65% (51.34 kJ/kg_{H2O}) as the air flow rate changed from 10 m^3/min-m^3 to 17.5 m^3/min-m^3.

Fuel energy consumption per unit of water removed increased in the conventional system and decreased in the recirculating system in the same air flow rate range mentioned above (Fig. 12). Meanwhile, the fuel energy saving by using the recirculating system changed from 38.42 (2189.90 kJ/kg_{H2O}) to 69.54% (5548.58 kJ/kg_{H2O}).

Total energy consumption went up with air flow rate in

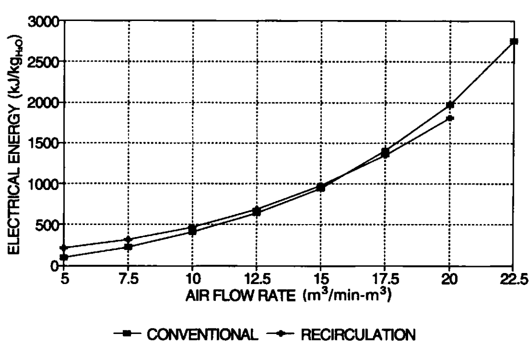

Fig. 11. Electrical energy consumption per unit of water removed vs. air flow rate.

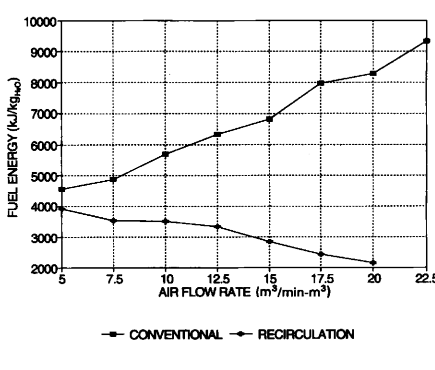

Fig. 12. Fuel energy consumption per unit of water removed vs. air flow rate, based on fuel energy content of 25449.6 kJ/L.

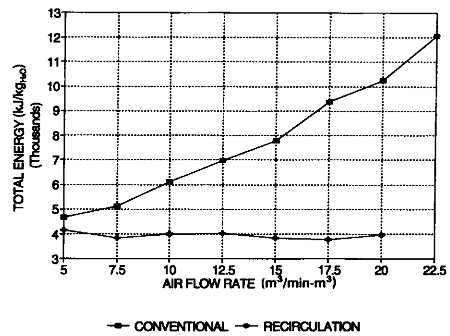

Fig. 13. Total energy consumption per unit of water removed vs. air flow rate, based on fuel energy content of 25449.6 kJ/L.

the conventional system and remains relatively constant in the recirculating system (Fig. 13). The total energy saving in the recirculating system increased from 34.77 (2123.62 kJ/kg_{H2O}) to 59.68% (5599.92 kJ/kg_{H2O}). The recirculating system had a stable low energy consumption over the entire air flow rate range.

Considering the particular case of an air flow rate of 10 m^3/min-m^3, the simulated energy savings of 34.77% compared favorably with the 40% estimate of Young *et al.* (7) based on experimental results. There were two reasons for the differences. First, the actual drying season for experiments usually began in late September, a few days earlier than the simulation drying season. Therefore, the system received more benefit from solar radiation and required less energy from the heaters. Secondly, the simulation model for the recirculation system assumed no transfer of water vapor from the main drying room except in the exhausted air. However, observations during experimental tests confirmed that there was moisture diffusion through walls and cracks when there was no gross movement of air out of the system. Thus, the simulated savings for the recirculating system compared to the conventional would be expected to underestimate the experimental savings.

Conclusions

The effect of air flow rate on drying times and costs in a solar-assisted partial air recirculation peanut drying facility was significant. When the air flow rate was increased, the seasonal drying capacity, the electrical and fuel consumption, and total or specific drying cost increased as well. On the other hand, drying time for each wagon decreased and total energy consumption remained relatively constant. The specific cost at higher air flow rate in the recirculating system was less than that in the conventional system with lower air flow rate. If based only on these operational factors and specific cost, the only conclusion which could be drawn is that the recirculating system has an economic advantage. The best value of air flow rate depended on many factors, the specific cost being just one of them. The recommended value cannot be given at present. However, further study should focus on fixed cost of the two systems and the optimal value of air flow rate in order to get both high energy efficiency and high drying rate.

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