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IN-PLANT STUDY OF POTENTIAL FOR AIR RECYCLING IN FRESH FRUIT DRYING[1]

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Abstract. **Temperatures of ambient air and of the exhausted air from fresh citrus dryers were monitored throughout a 5-month period at a commercial citrus packinghouse. Additionally, energy consumption for drying was measured through collection of steam condensate from dryer radiators on two 29 metric ton (70 pallet box/hr) lines. With current commercial practice, energy consumption was measured at 5.65 x 10⁵ kJ/hr (5.36 x 10⁵ BTU/hr) for a single 70 pallet box/hr line. Assuming air would be heated to 60°C (140°F) for fruit drying, calculations were made using either heated air exhaust or ambient air. The drying potential would be reduced by an average of 6.5% by recycling the air but recycling air reduced energy requirements by 29.6%. A table to estimate economic break-even for energy expenditures is presented.**

Energy conservation represents the most straightforward and easily implemented approach to reduce consumption of fossil fuels. In industrial applications, thermal insulation, optimum productivity scheduling and heat recouperation are examples of techniques or processes that are readily adaptable. The majority of Florida packinghouses depends on fossil-fueled steam boilers for process heat in fruit drying. The fruit drying precedes solvent-based waxing and follows water wax applications. The drying operation is critical for 2 reasons: first, it is a time limiting element on the fruit handled and, secondly, it accounts for appreciable operating expense for both fuel and waxes. These 2 factors, energy reduction and fruit throughput are somewhat conflicting. Air recycling to reduce energy consumption will decrease the drying potential of heated air (1) and hence, the resulting packing line capacity. One extreme case but a normal Florida practice would be no heat recovery by introducing ambient air into single air pass dryer. The alternate extreme is a completely enclosed dryer where heated air would approach 100% relative humidity or essentially zero drying potential.

To investigate the potential for recycling air, temperatures were monitored at a commercial packinghouse during the 1978-79 packing season. Temperatures adjacent to the dryers, i.e., air that could be recycled and outside temperatures were measured. Additionally, energy consumption of 2 packing line dryers was measured to provide baseline data on current energy consumption and to provide an economic basis for capital expenditures to reduce energy operating costs.

Experimental Methods and Basic Calculations

The following measurements were made weekly: outside wet and dry bulb temperatures, dryer area wet and dry bulb temperatures, steam condensate flow rate and the pallet box dumping rates. Tests were initiated December 1978 and continued through May 1979 at Haines City Citrus Growers Association packinghouse. The 2 packing lines had the same rated capacity, ca. 70 pallet boxes (29 metric tons) grapefruit/hr. Pregraders, washers, water eliminators, fungicide applications, dryers and solvent-based waxers were located in the same section of the building. Dryers were typical of those found in Florida packinghouses with no air recycle and 1 to 2 layer fruit depth through the dryer. Dryer heat exchangers were controlled by thermostatically regulated steam traps. Steam was supplied from a remotely located boiler.

Fundamental calculations were made to compare energy requirements and drying potential. The energy to elevate either outside or inside air to a desired heated temperature was estimated from:

$$\dot{q} = \dot{m}\, c_p\, (T_H - T_a) \tag{1}$$

with $\dot{q}$—unit heat flow rate, $\dot{m}$—unit mass flow rate, c_p—air mass specific heat, T_H—heated air temperature and T_a—ambient air temperature. For this analysis a heated air temperature of 60°C (140°F) was used.

Drying potential of either outside or inside air was based on humidity ratio difference (2).

$$HRD = (H_s - H_a) \tag{2}$$

with HRD—humidity ratio difference, H_s—humidity ratio at wet-bulb saturation and H_a—humidity ratio at test conditions.

Energy extracted from the radiator heat exchanges was assumed to be latent heat only. Hence, the energy consumption rate was:

$$\dot{E} = \dot{m}_s\, h_{fg} \tag{3}$$

with $\dot{E}$—energy rate, $\dot{m}_s$—mass flow rate of steam condensate and h_{fg}—latent heat of vaporization for steam.

Results and Discussion

Sampled psychrometric statepoints for air adjacent to the dryers and outside the packinghouse are shown in Fig. 1. As exemplified by the arrow on Fig. 1, air adjacent to the dryers showed a marked increase above outside air in both dry bulb (db) and wet bulb (wb) temperatures. Increase in wb temperature can also be interpreted as a gain in the absolute humidity since no dehumidification occurred. Outside temperatures ranged from 16.1°C db, 8.3°C wb to 30.0°C db, 22.0°C wb while adjacent to the dryers, temperatures ranged from 26.1°C db, 16.9°C wb to 41.5°C db, 28.0°C wb.

Using a computer program, the energy required to elevate either inside or outside air to 140°F (60°C) was calculated from Eq. 1. Also, differences in drying potential based on a humidity ratio difference were computed. Results have been summarized in Table 1. For the sampling period, utilizing exhaust air from the dryers diminished the resultant drying potential after temperature elevation to 140°F (60°C) by an average 6.5% over the level for using the outside air. However, energy requirements were markedly reduced by an average 29.6%. Maximum HRD reduction was 9.9% while minimum additional energy input for outside air was 21.9%. Further energy reductions would be realized if return ducts were specifically installed to partially recycle dryer exhaust air.

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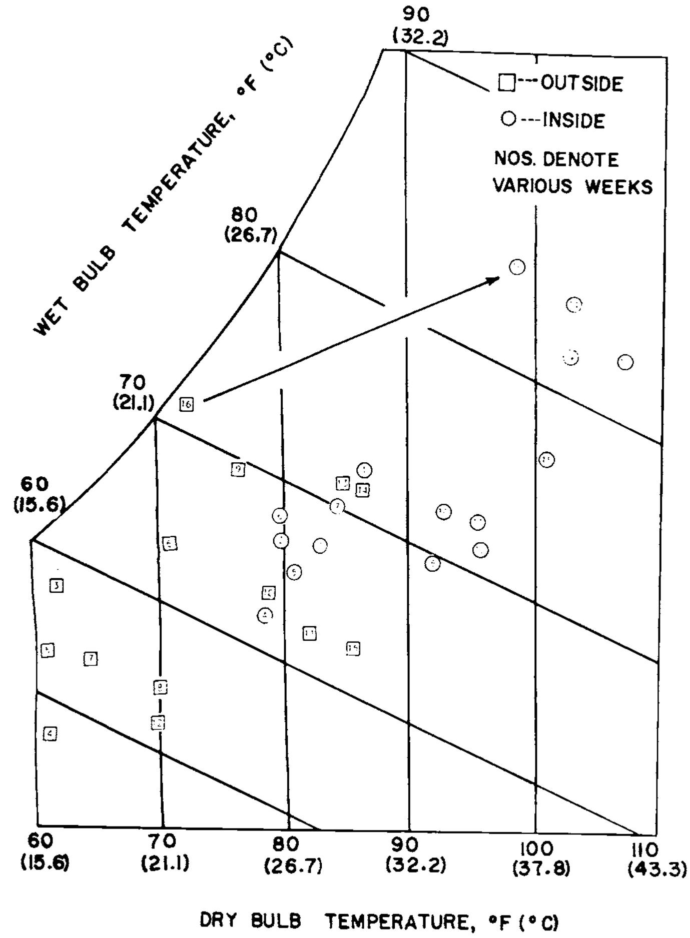

Fig. 1. Sampled psychrometric conditions for air adjacent to fruit dryers and outside air. Arrow denotes typical dry and wet bulb temperature increase.

Table 1. Statistical summary of energy and drying ratios for inside and outside air locations.

Ratio	Mean	Standard deviation	Range
E_{out}/E_{in}[z]	1.42	0.14	1.28 - 1.69
HRD_{out}/HRD_{in}[y]	1.07	0.03	1.01 - 1.11

[z]E_{out}—energy requirement utilizing outside air, E_{in}—energy requirement utilizing inside air.
[y]HRD_{out}—resultant humidity ratio difference using outside air, HRD_{in}—resultant humidity ratio difference utilizing inside air.

It should be noted that the above tests were conducted from December 1978 to June 1979 of the 1978-79 citrus packing season. Certain meteorological conditions may be encountered that more severely restrict drying than those measured. Also, fruit or surface moisture temperatures close to the saturated wet-bulb temperature were assumed for establishing the humidity ratio difference. This may not be valid when fruit has been previously warmed in degreening rooms.

Energy consumption, calculated from steam condensate, averaged 545,400 BTU/hr (8,620 kJ/min) and 527,400 BTU/hr (8,330 kJ/min) for dryers on the 2 packing lines. At 1,300 operating hours per year, boiler conversion efficiency of 0.8 and steam cost of $5/1,000 lb. steam ($0.011/kg steam), yearly energy operating cost for dryers on these packing lines would average $4,493 each.

A final consideration is installation cost for air recycling equipment to further reduce energy consumption and the expected return for that investment. In Table 2, a lending rate of 13.5% was assumed with energy costs escalating at that level or either 2.5 or 5.0 percentage points above the borrowing rate. Simple payback time, $ expended/$ yearly return, for the 3 investment levels ($1,000, $2,500, $5,000) would be 1.05, 2.39 and 4.78 years, respectively. Small investments of $1,000 or $2,000 could be readily justified if a 30% energy reduction is realized. However, investments greater than $5,000 have economic break-even levels greater than the conventional 2 to 3 year period accepted by industry. Hence, only low cost ducting systems with minimal controls could be justified, especially in modular built dryers where each module would require separate damper and control units.

Table 2. Economic breakdown for various capital outlays and energy inflation rate.[z]

Investment	Interest rates	Energy inflation	Economic break-even
	%	%	yr
$1,000	13.5	13.5	1.09
	13.5	16.0	1.09
	13.5	18.5	1.08
$2,500	13.5	13.5	2.71
	13.5	16.0	2.67
	13.5	18.5	2.62
$5,000	13.5	13.5	5.43
	13.5	16.0	5.18
	13.5	18.5	4.97

[z]Calculations based on: $5/1,000 lb. steam, 30% energy reduction, 536,000 BTU/hr current consumption, 1,300 hr/yr operation.

In summary, the increases in temperature and moisture level of exhaust air from citrus dryers indicate significant proportions of dryer air can be recycled with minimal losses in drying potential. In a commercial plant, sampling of the exhaust air stream indicated a 29.6% energy reduction by air recycling accompanied by a 6.5% decrease in drying potential expressed as a humidity ratio difference. Economic calculations for installation of air recycling ducts and appropriate controls indicate investment levels must be low to achieve reasonable economic break-even periods.

Literature Cited

1. Keey, R. B. 1972. Drying: principles and practices. Pergamon Press. Oxford, U.K.
2. Miller, W. M. 1978. Surface moisture drying characteristics of citrus fruit. *Trans. ASAE.* 21:1237-1241.