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

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Additional index words, energy, energy conservation.

Abstract. Temperatures of ambient air and of the ex-
hausted air from fresh citrus dryers were monitored through-
out 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 10⁶ kJ/hr (5.36 x 10⁶ 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 expendi-
tures 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 recuperation
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 tempera-
tures 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 thermo-
statically 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:

\[ q = \dot{m} \cdot c_p \cdot (T_H - T_a) \]  

with \( q \)--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 tempera-
ture of 60°C (140°F) was used.

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

\[ \text{HRD} = (H_s - H_a) \]  

with HRD--humidity ratio difference, \( H_s \)--humidity ratio
at wet-bulb saturation and \( H_a \)--humidity ratio at test condi-
tions.

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

\[ E = \dot{m} \cdot h_{fg} \]  

with \( E \)--energy rate, \( \dot{m} \)--mass flow rate of steam condensate
and \( h_{fg} \)--latent heat of vaporization for steam.

Results and Discussion

Sampled psychrometric state points 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, tempera-
tures 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 re-
sultant 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.
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.

<table>
<thead>
<tr>
<th>Ratio</th>
<th>Mean</th>
<th>Standard deviation</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_{\text{out}}/E_{\text{in}}$</td>
<td>1.42</td>
<td>0.14</td>
<td>1.28 - 1.69</td>
</tr>
<tr>
<td>$\text{HRD}<em>{\text{out}}/\text{HRD}</em>{\text{in}}$</td>
<td>1.07</td>
<td>0.03</td>
<td>1.01 - 1.11</td>
</tr>
</tbody>
</table>

$E_{\text{out}}$—energy requirement utilizing outside air, $E_{\text{in}}$—energy requirement utilizing inside air.

$\text{HRD}_{\text{out}}$—resultant humidity ratio difference utilizing outside air, $\text{HRD}_{\text{in}}$—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 $4,499 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, $P$ expended/$P$ 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 rates.

<table>
<thead>
<tr>
<th>Investment</th>
<th>Interest rates</th>
<th>Energy inflation</th>
<th>Economic break-even</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>%</td>
<td>%</td>
<td>yr</td>
</tr>
<tr>
<td>$1,000</td>
<td>13.5</td>
<td>13.5</td>
<td>1.09</td>
</tr>
<tr>
<td>$2,500</td>
<td>13.5</td>
<td>15.5</td>
<td>2.71</td>
</tr>
<tr>
<td>$5,000</td>
<td>15.5</td>
<td>16.0</td>
<td>4.97</td>
</tr>
</tbody>
</table>

$^+$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