Improving Drying Uniformity in Concurrent Flow Tunnel Dehydrators

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ABSTRACT

The moisture content variation in fruit dried in concurrent flow tunnel dehydrators is dependent upon the uniformity of the air flow entering the wet end of the tunnel. Improvements in dehydrator performance were obtained by using a flow diverter and turning vanes to produce a more uniform flow distribution and thereby reduce the moisture content variation. Experiments conducted in prune tunnel dehydrators indicate that the modification can reduce the range in final fruit moisture content by approximately 40%.

INTRODUCTION

Prunes and many other types of fruit are dried in truck and tunnel dehydrators similar to that shown in Fig. 1. The technology was first introduced for prune drying during the 1920's and some of the first research on drying was conducted by Cruess and Christie (1921) and Christie and Ridley (1923). Later Christie and Nichols (1929) recognized that drying time was controlled by factors such as air temperature, air humidity, fruit variety, pretreatment of the fruit, and air speed over the fruit. Non-uniform air flow across the frontal area of the car was noted as a factor causing variable moisture among the fruit leaving the tunnel, however, no solutions were offered to correct the non-uniform air flow. Mrak (1938) noted that uniform air flow is important in producing uniform drying and depicts air baffles in a dryer schematic but does not describe how to design a dryer to obtain a uniform air flow. Nearly all tunnel dehydrators for prunes constructed within the last fifteen years are patterned after a design developed by Rodda and Gentry (1969). Air flow uniformity was not incorporated as a design consideration. Though a few tunnels have turning vanes in the top air chamber of the dehydrator, the vast majority of tunnel dehydrators for prunes have no special provision to ensure uniform air flow.

In spite of the lack of research on air flow uniformity, it is apparent that this is a problem in the industry. Dryer operators regularly observe wide variations in fruit moisture content within individual cars. In order to ensure that the wettest fruit has reached a safe moisture content, much of the fruit is over dried. In some operations, wet concurrent flow prune dehydrator.

EXPERIMENTAL PROCEDURE

During the 1982 drying season, air flow distribution tests were conducted at a typical concurrent tunnel dehydrator for prunes based on the design of Rodda and Gentry (1969). The air flow patterns were obtained from photographs of a wire grid with small yarn tufts attached (Pope, 1966). The magnitude of the air velocity component parallel to the tunnel was obtained using a 0.79 cm pitot static probe and inclined manometer. The pitot static probe was located between the trays (3.2 cm spacing) and 23 cm downstream from the face of the first car. These measurements were made with both fruit-laden and empty cars. The tests revealed the nature and location of air flow non-uniformities and were used to judge the performance of modifications to improve the air flow distribution. The modifications were selected from known control methods (suction, screens, vanes, etc.) developed to prevent flow separation in wind tunnels and diffusers (Cheng, 1976). These modifications tested included screens placed in front of the first car, a suction slot located just above the front cars, and a flow diverter and turning vanes as shown in Fig. 2. The flow diverter directs the air upward, allowing the first set of vanes to turn the flow 90 deg. while leaving enough space to locate the lower set of vanes above the pathway of the cars. Further, the positions of the lower vanes can be adjusted for an individual tunnel flow to achieve optimum results, including elimination of a
portion of the flow asymmetry which is produced by fan swirl (though this effect is best removed using a flow straightening device attach to the fan). The best results were obtained with the turning vane configuration and the worst with the suction slot. The suction pressure was obtained using a duct connected to the upstream side of the fan and was insufficient to control the flow. Though the screen performance was comparable to that of the vanes, the additional pressure loss and need to move the screens during tunnel filling made it a less desirable modification.

The following season (1983), two tunnels were modified to improve the air flow using turning vanes described above. The moisture content of the dried fruit was monitored to determine if the modifications resulted in less moisture variation than that of the conventional tunnel design. Twelve moisture samples were taken at uniformly distributed locations on each car of dried fruit. Fruit moisture was measured with an industry standard Dried Fruit Association meter. Modified and control tunnels were operated at hot end temperatures of 74 ± 4 °C and wet bulb temperatures of 49 ± 3°C. All fruit remained in the dehydrator for 16.3 h and all tests were done with French variety prunes.

RESULTS AND DISCUSSION

The air flow patterns in the conventional tunnel are shown in Fig. 3. Fig. 3a illustrates our estimate of separated flow regions near the center line produced as the flow is turned through 180 deg., while Fig. 3b shows the twin counter-rotating vortices in the cross flow observed in photographs of the tuft pattern. Note that the position of low air speed is coincident with the location of the centers of the vortices and where the operator observes the wettest fruit. The air speed distribution is shown in Fig. 4 and compares qualitatively with measurements with empty cars and data reported by Gentry et al. (1965). Due to errors in pitot tube alignment, visual recording of the manometer reading, etc., the data are expected to be accurate to ±0.25 m/s (±50 fpm). The air speed entering the first car shown in Fig. 4 varies considerably with high velocities near the floor of the tunnel and low velocities near the upper center of the cars. Discrete data points...
Fig. 5—Air flow distribution entering the first car of a tunnel with the turning vane and flow diverter configuration of Fig. 2.

are shown connected with straight lines in Fig. 4 and results for the two front cars are not connected because the flow is blocked by framing at the center of the tunnel. Note that the air flow distribution is much more uniform leaving the dry end of the tunnel as a result of adjustments which take place within the tunnel. However, the flow field has its strongest influence during the convective phase of drying at the wet end. Air speed measurements made in a modified tunnel are shown in Fig. 5. Air speed ranged from 6.1 to 8.8 m/s (1190 to 1730 fpm) in the modified tunnel vs. 3.7 to 11.4 m/s (720 to 2250 fpm) for the conventional tunnel. The effect of the counter-rotating vortices was weakened as a comparison of Figs. 3 and 5 indicates.

The results of the dried fruit moisture testing conducted during the 1983 season are summarized in Table 1. These data represent a total of 12 tests for each of the modified and conventional configurations. The modifications were found to reduce the range in fruit moisture content from an average of 12% moisture in the control tunnels to an average of 7% in the modified tunnels. The standard deviation of the moisture content was reduced by approximately the same proportion as the last column of the table shows. The reduction in range is significant at the 99% confidence level as measured by a t test. The data also indicate that there was no significant difference in the average fruit moisture for the two configurations. Also note that the differences in average speed are within the range of variations among the tunnels without modifications. Also, the dryer operator found that the tunnels with the air flow modifications eliminated the need to redry fruit, resulting in increased drying capacity and possibly a small reduction in energy use, though this parameter was not studied.

### SUMMARY

A study of the fluid dynamics of concurrent flow tunnel dehydrators has revealed that non-uniform air flow is responsible for observed variation in dried fruit moisture content. A statistically significant improvement in moisture content uniformity was achieved by modifying the air flow entering the first car through the use of turning vanes and a flow diverter. The air flow modifications reduced the range of dried fruit moisture content by over 40% compared to the output of a conventional concurrent dehydrator.

### References