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EVALUATING COMMERCIAL FORCED-AIR PRECOOLERS

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Abstract. **Forced-air cooling of green peppers in Florida has become an important post harvest procedure for maintaining quality. In response to packinghouse operator concern over forced-air cooling system performance, procedures were developed to determine how well these systems perform and to provide recommendations for short term and long term improvements. System performance was assessed by measurement of static pressure drop, air velocity, and cooling rate during commercial forced-air cooling of green peppers. Recommendation for increased efficiency, which can be accomplished with minimal cost and increased management, include sealing air leak areas to force additional air through products, improving carton stacking configurations/orientation, modifying pallet-tunnel length and width, and proper temperature monitoring. Recommendations requiring more time and cost included improvement in carton design, increased fan capacity, and increased cooling capacity.**

Commercial forced-air precooling (2, 3, 4) of bell peppers was established in Florida in 1982, and has become an important post harvest procedure for maintaining quality. In response to request from packinghouse operators concerning the performance of their forced-air coolers, this study was initiated with the objectives to develop procedures to determine how well these systems perform and to provide recommendations for short term and long term improvements.

Materials and Methods

Packinghouse A, in Immokalee, was visited during May 1990, in an effort to gather preliminary data. The cartons, pallet configurations, and forced-air cooling procedures were noted. Static pressure across the pallets was measured using a digital manometer. Sample temperatures were measured using a hand-held thermocouple reader. Velocities through the carton vent holes and the opening in the pallets were measured using a hot-wire anemometer. The velocity measurements indicated a large quantity of cold air passed under the cartons through the openings in the pallets (Fig. 1). The principle of path of least resistance is a key physical relationship which requires that the openings in the pallets be blocked in order to increase the air flow through the carton vents. When told of this problem Packinghouse A personnel decided to place boards (3 meter long 2 by 4's) by the pallets along the outside length of the cooling tunnels. A second effort involved placing a 30 cm (12 inches) wide plastic material, with one sticky side, over the pallet sides along the entire perimeter of the tunnel. Since the end of the spring crop was near, no further data was collected until the fall crop.

In November 1990, Packinghouse A and Packinghouse B were visited twice and cooling temperature, velocity, and static pressure data were recorded. The pressure was measured in the same way, but the velocity was measured using a vane anemometer and the temperature was measured using a datalogger and 30-gauge thermocouples. The cooling temperature was only measured at Packinghouse A, since peppers were not packed at Packinghouse B during the experimental visits.

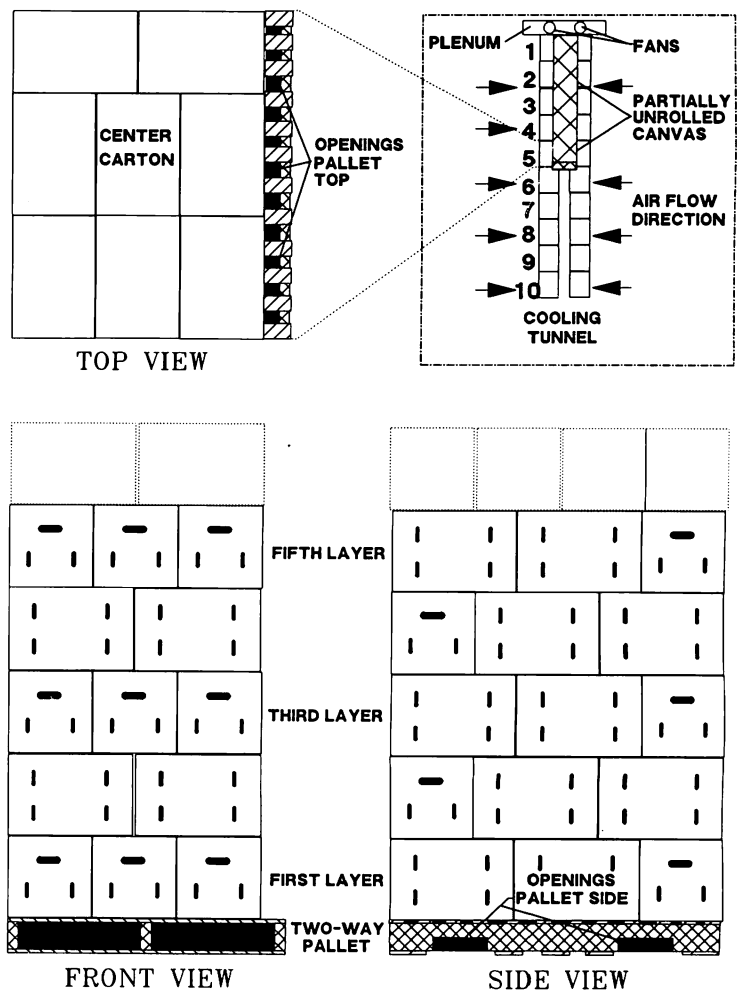

Fig. 1. Carton configuration on pallets.

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The temperature measurement was accomplished using 63 thermocouples, 56 inserted approximately 2.5 cm (1 inch) into the blossom end of peppers, which were placed in cartons on the third layer of the first, fifth, and tenth pallets of a forced-air cooling tunnel. Nine peppers with thermocouples were placed in the center carton while one or two peppers with thermocouples were placed in six of the other cartons on the third layer of the first, fifth, and tenth pallets (Fig. 1). Two thermocouples measured the air temperature in the middle of the center cartons on the third layer of the first and tenth pallets, two thermocouples measured the air temperature leaving the first and tenth pallets, while three thermocouples measured the cold room air temperature, which was the air temperature entering the cartons.

The static pressure was measured across the ten pallets (six for Packinghouse B) and at the end of the tunnel opposite the fan. The air velocity was measured inside the tunnel for the carton vent holes on the first, third, and fifth layer of cartons and for the side and top openings in the pallets of the first, fifth, and tenth pallets. (First and sixth pallets for Packinghouse B). The fan velocity was measured across the fan plenum opening. The static pressure and velocity were measured before and after the addition of plastic to the pallet sides along the perimeter of the cooling tunnel.

Results and Discussion

The carton configuration on the pallets is shown in Figure 1. This pattern alternated for five layers. Packinghouse B also added a sixth layer of cartons all end to end. Packinghouse A used two rows of pallets, ten pallets long for each forced-air cooling tunnel (Fig. 1). Each pallet held 40 cartons. Packinghouse B used two tunnels (4 rows of pallets) for each forced-air cooler, each tunnel 6 pallets long. Each pallet held 48 cartons and each carton contained approximately 12.7 kg (28 lb.) of pepper. Additional studies should be conducted to determine how varying the number of pallets, height of the cartons on the pallets, tunnel width, and similar factors effect the performance of the air handling and cooling systems.

The 1-1/9 bushel cartons were approximately 30 cm (12 inches) high, 30 cm (12 inches) wide, and 46 cm (18 inches) long. The end vents consisted of a horizontal hand hole vent and two vertical slot vents. The side vents consisted of four vertical slot vents. Packinghouse A cartons also had small circular holes centered on the top and bottom edges.

For Packinghouse A the end vents, side vents, and total vent percent openings were 4.1, 2.8, and 3.3, respectively. The calculated percentages were 3.1, 1.1, and 1.9, respectively, for Packinghouse B. The recommended carton percent vent opening is 5% in the airflow direction for forced-air cooling (1, 4). Both packinghouses should increase the area of the carton vents to achieve the recommended percent vent opening, therefore reducing the pressure drop across the cartons and increasing the air flow through cartons. Larger holes produce lower pressure drops than several smaller holes of the same area.

For Packinghouse A and B, the cartons were placed such that the side vents aligned with the side vents of the adjacent carton and the end vents aligned with the end vents of the adjacent carton. In some applications, the stacking patterns require ends of cartons to align with the sides of adjacent cartons and the carton vent locations must be designed accordingly. If the vent holes on adjacent cartons do not match up, a major disruption of air flow occurs. This situation should be avoided. With the slender vertical slots on the ends and sides, offset of the carton by as little as 1/4 inch could result in vent hole misalignment. This is another reason for selecting large rather than small vent holes, since the larger holes would allow partial vent alignment even when the cartons are not aligned correctly.

In addition to the side openings in the two-way pallet shown in Figure 1, the bottom layer of cartons did not completely cover the surface of the pallet, leaving openings between boards on the top of the pallet which also served as paths for air flow under the cartons. Significant air flow was noted as a result of the open pallet surfaces. Normally the cartons were stacked flush with one side of the pallet, while the other side exposed the surface of the pallet. The side with the exposed pallet surface should be placed so that the exposed surface is on the tunnel side.

The pallets were placed end to end to form each side of a cooling tunnel. It is important that the pallets are placed such that very little gap exists between the cartons of adjacent pallets. Otherwise another path is created to bypass the cartons. Velocity measurements indicated significant air flow through such gaps, particularly when the plastic was installed to seal the side openings of the pallets.

The use of the lumber placed against the sides of the pallets at Packinghouse A did not significantly decrease the air flow through the pallet openings. Apparently the rigid structure could not properly seal the openings in the pallets. The importance of sealing the openings in the pallets is illustrated in Figures 2 and 3. The static pressure drop with and without plastic across the pallets (outside to inside of the cooling tunnel) at the center of each pallet and at the end of the tunnel away from the fan was used as a measure of the effectiveness of sealing off the by-passed air. The pressure drop for Packinghouse A was nearly doubled. Since the pressure varies with the square of the velocity, doubling the pressure would result in a 40% increase (square root of 2) in the velocity. The increase in the pressure drop for Packinghouse B (Fig. 3) also indicates the benefit of sealing the pallet openings.

To further illustrate the advantage of sealing the pallet openings, the velocity through the pallets (measured inside

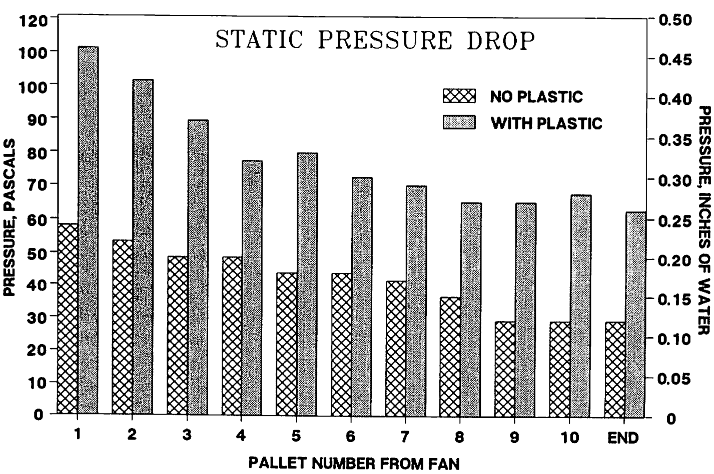

Fig. 2. Static pressure drop, Packinghouse A.

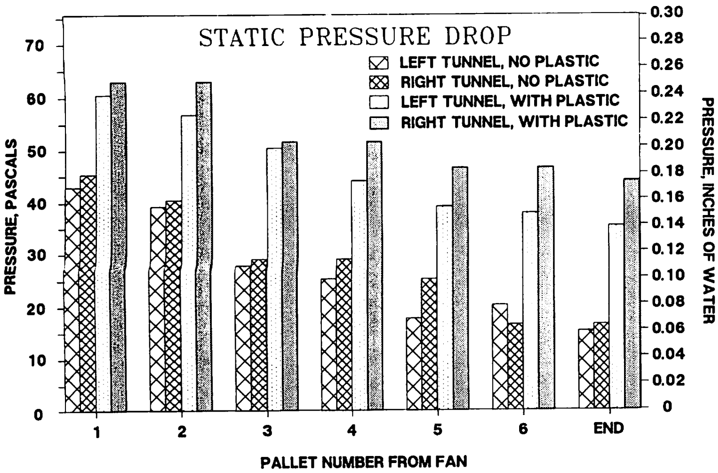

Fig. 3. Static pressure drop, Packinghouse B.

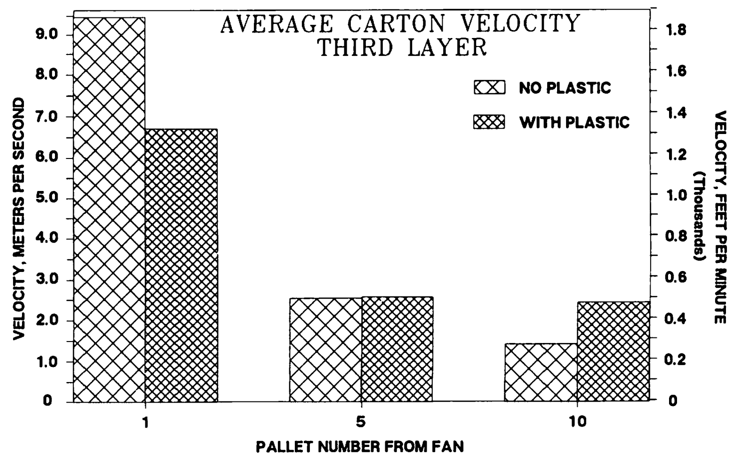

Fig. 5. Average carton velocity third layer.

the tunnel) before and after the addition of plastic is illustrated in Figure 4. The velocity through the first pallet from the fan was reduced by 33% while the velocity through the fifth pallet was reduced by 75%. Figure 5 illustrates the average velocity exiting the vents of a selected carton on the third layer of the first, fifth, and tenth pallets from the fan. The change in velocity as a result of the addition of plastic has a "seesaw" affect with the velocity of the first pallet decreasing, while velocity of the tenth increasing and the velocity of the fifth pallet remaining the same. The change in velocity would produce improved cooling uniformity between pallets.

The sealing of the pallet openings has been shown to be successful. However, can this be accomplished successfully on a commercial scale operation? The boards did not work, while the plastic worked well. During studies at Packinghouse B, not enough plastic was available to cover the entire perimeter of the four rows of pallets. All that could be found to use was a roll of kraft paper towels. The paper towel was used as a satisfactory substitute. An alternative to plastic or paper would be to pour concrete curbs which would be on the outside of the pallets. A rubber material could be added to help complete the seal. However, in addition to significant construction effort and expense, in such a rough environment of forklift operations success of this idea might be short lived. The use of plastic as described works well but placing and removing the plastic requires time and if the plastic is not reused then purchase and disposal would present problems. Personnel from Packinghouse A suggested that a retractable plastic roll attached to the wall adjacent to the first pallet could be used. This system would work like a pull-down window blind or like a projector screen in that it could be rolled away after use. No sources for such an item have been located. A simple idea for sealing the pallet would be to use plastic to cover the sides not normally used for the forklift blades and the top of the pallet. This could be accomplished inexpensively with in-house personnel using purchased or salvaged plastic and staplers or tape. When discussing this idea with Packinghouse B, another method was suggested. The cartons are shipped to the packinghouse wrapped in a large sheets of cardboard. This scrap cardboard could be stapled to the pallet tops and sides. Presently, peppers are not shipped on pallets, so the modified pallets would be used only inside the packinghouse. Future purchases of new pallets could be of pallets with solid sides and tops rather than the two-way type.

The cooling curves for the average temperature of the third layer of cartons on first, fifth, and tenth pallets are shown in Figures 6 and 7. As expected the first pallet cooled at a faster rate, while the fifth pallet had the second fastest

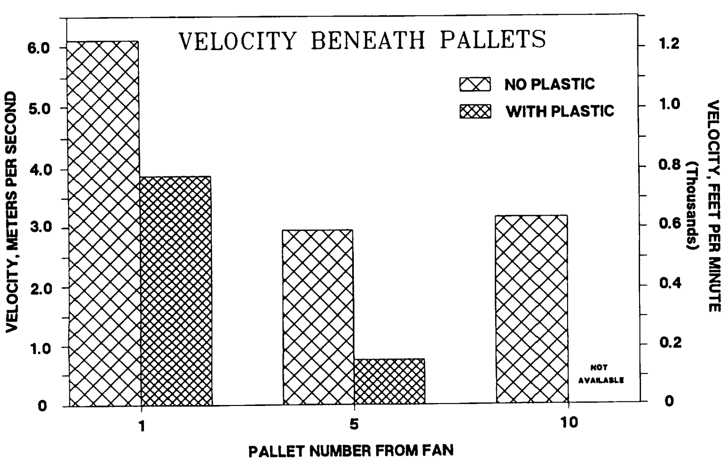

Fig. 4. Velocity beneath pallets.

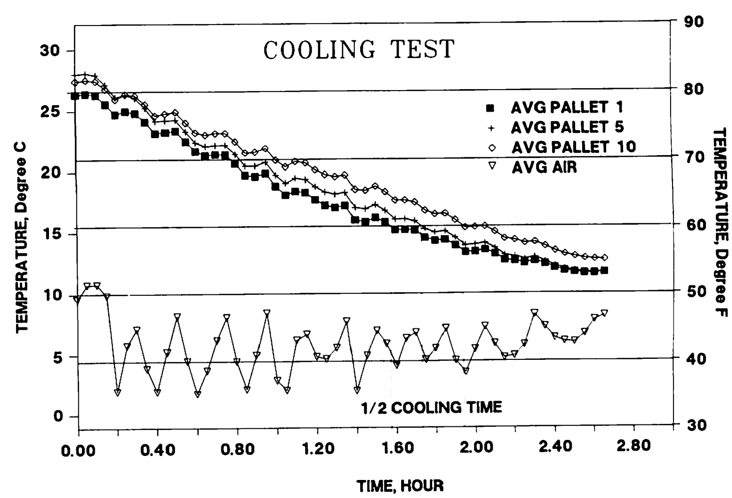

Fig. 6. Cooling test, 29 Nov 90.

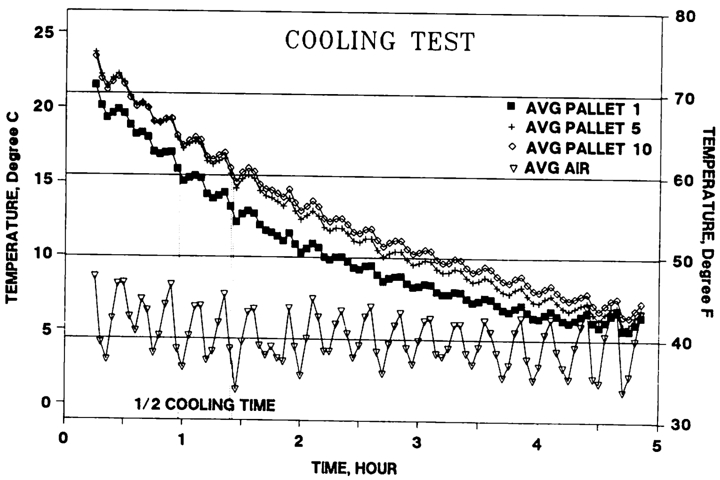

Fig. 7. Cooling test, 15 Nov 90.

cooling rate, but the tenth pallet did not cool much slower than the fifth pallet. Packinghouse A maintained an average temperature of approximately 4.4°C (40°F) which is excellent and appeared to provide adequate cooling capacity. For this season of the year the initial pulp temperatures were only in the 26.7°C (80°F) range. Additional test will be made during the spring when initial temperatures can exceed 32.2°C (90°F).

The time required to remove one half the difference between the initial pulp temprature and the cooling medium temperature is known as the half cooling time (3, 5). The half cooling time for the cooling curves in Figure 6 would be the time at which the temperature reached approximately 15.6°C (60°F). The first pallet would achieve this in 1.6 hours, while the fifth pallet would take 1.7 hour and the tenth would take 1.9 hours. The data in Figure 7 show a longer cooling time. The initial data are not shown but the initial pulp temperature was approximately 26.7°C (80°F). This test was conducted on a different cooling tunnel and the first pallet cooled at a faster rate than the fifth and tenth pallets, with the tenth pallet cooling at a slightly slower rate than the fifth. The half cooling time for this data would also be achieved when the temperature reached 15.6°C (60°F). The first pallet would reach the half cooling time in 1 hour while the fifth and tenth pallets would reach the half cooling time in 1.4 hours.

Both cooling test were conducted with no plastic added to the pallets. Although the plastic was installed after 3.5 hours for the test shown in Figure 7, no conclusions were drawn. A comparative cooling test between a cooling tunnel without plastic and a cooling tunnel with plastic will be conducted in the future to determine how much the application of the plastic can increase the cooling time. Cooling tests are also planned for Packinghouse B and other forced-air coolers.

Both Packinghouse A and B use dial-type thermometers to pulp the pepper temperature in order to determine when precooling has been completed to the desired level (for example 15.6°C (60°F)). Packinghouse A samples the pulp temperature at the outer end of the tenth pallet of the third or fourth layer of cartons by inserting the thermometer into a pepper through a vent opening in the carton. Packinghouse B samples the pulp temperature at several locations using a similar technique of inserting the thermometer into peppers exposed by the carton vents. Additional work is needed before a "best" method for sampling temperature can be recommended.

This study has pointed out several methods to increase the efficiency of forced-air precoolers for peppers. Recommendation for increased efficiency which can be accomplished with minimal cost and increased management include sealing air leak areas, particularly through the pallets, to force additional air through products, and improving carton stacking configurations/orientation. Modifying pallet-tunnel length and width and proper temperature monitoring are two other methods for improving efficiency that will be studied further. Recommendations requiring more time and cost included improvement in carton design, increased fan capacity, and increased cooling capacity. Of these three, the design of the carton with particular attention to the percent vent openings should be addressed first. Increasing the fan and cooling capacity should be considered only after all the above mentioned changes have been accomplished.

Acknowledgements

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