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CONTAINERIZED CURING OF TOBACCO

by

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SUMMARY: Tobacco was successfully cured in pallet-size containers loaded to a density of 8.4 lb/ft^3 (141 kg/m^3) with a conventional automatic tobacco primer. Measurement of temperature distribution throughout the containers revealed the position and rate of movement of the drying front. A maximum airflow of 75 CFM/ft^2 (22.5 $m^3/min/m^2$) was sufficient for a 6 day curing cycle.

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INTRODUCTION

Bulk curing [See for example, (1), (2), (3), (4), (5), (6)] reduced the labor requirement at the curing barn and opened the way for fully mechanized harvesting. With the acceptance of nonaligned leaf, came acceptance of a mechanical primer [See for example, (7), (8), (9), (11), (12), (13)] which primes the leaves from the stalk, and conveys them to a trailer carried on the rear of the machine. When filled, this trailer is taken to the curing barn, where the leaves are removed by hand, or with short tine pitchforks, and placed in bulk racks. The racks weigh 100-150 lbs. (45.4-68.1 kg) loaded, and are placed in the barn by two men usually with an electric hoist mounted on a swing arm over the door.

The primer is very efficient in removing and collecting the leaf material. A standard rack loading crew (two rack fillers and two handlers) often cannot handle the material at the same rate it is harvested, especially if the field-to-barn transport distance is short. Not only is loading a problem, but unloading the cured leaf is a time consuming operation requiring many individual activities. The objective of this study is to develop a materials handling system which will facilitate the loading and unloading of bulk curing barns.

Georgia has over 5000 bulk barns, the vast majority of which have been built in the last four years. It does not seem practical to design any system which will make these facilities obsolete. Any container to replace bulk racks must maintain a material distribution compatible with the air volume and static pressure in a bulk barn. It is desirable, but not critical, that the containers be designed such that an integer number will completely fill the space in a standard barn.

Suggs (10) has studied a large rack [approximately 4 x 4 x 3 ft (1 ft = 0.3 m)] to replace bulk racks. With his system a hoist mounted on a rail running the length of the barn was used to move the units into the curing chamber. A tobacco equipment manufacturer used the same handling procedure to handle racks [approximately 10 x 5 x 2 ft (1 ft = 0.3 m)], which were sized to occupy the entire cross section of a standard two-room, three-tier portable barn[1]. The racks in these two systems are light enough when empty to be handled by two men, and two men can use the hoist and rail to load the barn. Maneuverability of the empty racks and low equipment investment in the hoist are obvious advantages of these systems.

The decision was made to design a system which would use forklift equipment to handle the curing units, both in the field and in the barn. Forklift availability was constrained to equipment designed for utility size (35-50 hp) farm tractors, and used primarily for pallet handling in fruit and vegetable harvesting. This constraint limits the total weight of the loaded container to 1500 lbs (681 kg).

CONTAINER DESIGN

Container height in the curing position was fixed at 6 ft (1.8 m), the maximum height for bulk curing found by Shepherd[2], and width was fixed at approximately 5 ft (1.5 m) by the conveyor target area in the loading configuration (Fig. 1). A preliminary test showed that it was difficult to maintain a uniform density for a 4 ft (1.2 m) depth. The material settled and formed a positive density gradient from top to bottom. It was decided to use a design depth of 2.5 ft (0.75 m), as this would equate the container spatially in the curing position to six bulk racks, two on the bottom, middle and top tiers.

[1] Personal Communication. Mr. W. S. Wood, Project Engineer, Long Mfg. N. C. Inc., Tarboro, North Carolina.

[2] Personal Communication. Mr. J. L. Shepherd, Head Agricultural Engineering Department, University of Georgia Coastal Plain Experiment Station.

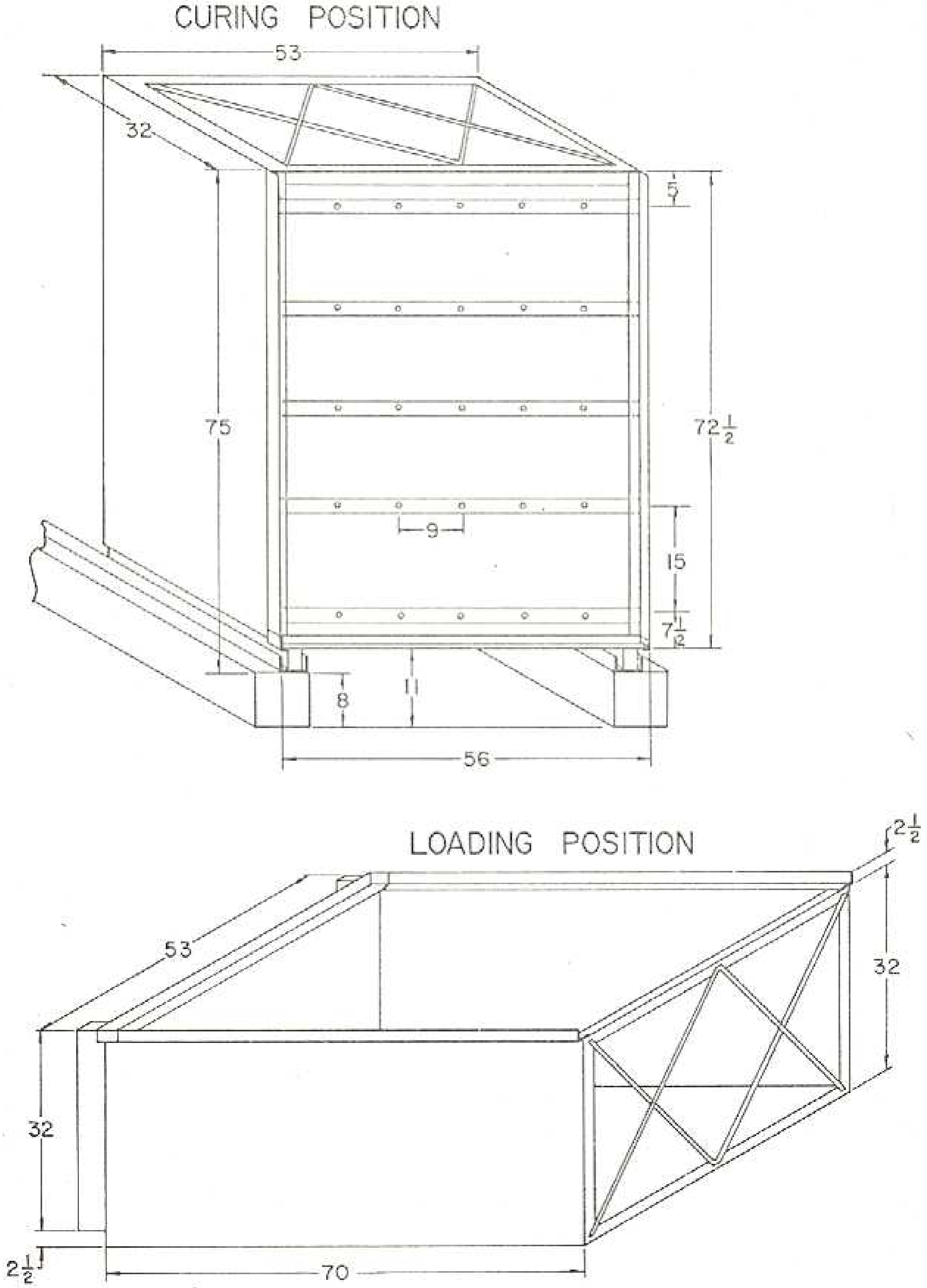

Figure 1. Container in curing and loading positions.

The tobacco must be supported in the container during the cure. Steel tubing [0.5 in. (1.25 cm) O.D., 0.375 in. (0.94 cm) I.D.] was welded to a bar to form a tine unit. Rods were fixed to the ends of the bar, and these were inserted in the square tubing used in the wall construction of the container (Fig. 2) to guide the bar into place. A hinged rail (Fig. 2) captured all bars simultaneously as it was locked down. This rail formed part of the rim around the front of the container which mated with the rear of a preceding container, and thus sealed the bottom and sides between containers in the curing chamber.

A pallet was built to protect the containers from the impact loads experienced during field handling. The containers could be constructed with less material, and therefore, at a lower cost by incorporating it into the system. Note the sloped guides (Fig. 3) to self-align the containers. Also, there are guides underneath to facilitate alignment when the unit is picked up with the three point hitch lift (Fig. 4) used in the field. The fork arms of this lift fit into a slot formed by the guides (Fig. 5); this locked the pallet in place so it could not be thrown from the lift. A hydraulic cylinder used as the third link on the three point hitch lift gave the tilt capability needed for vertical maneuvering.

METHODS AND MATERIALS

Tobacco was grown by a cooperating farmer using cultural practices recommended for machine harvest. A commercial, unmodified automatic tobacco primer was used to fill the containers. For the first and second primings, a worker stationed between the vertical conveyors on the machine used a short handle pitch fork to distribute the tobacco as it fell into the container. During the third and fourth primings redistribution was done at the end of a row where the container was lowered, and the mounds which had formed under each conveyor were leveled by hand.

A small bulk barn was modified by removing the drying floor and replacing the interior wall with an 8 in. (0.2 m) high foundation. A similar foundation was placed against one exterior wall. Steel channel was fastened to the top of the foundations to provide a sliding surface for the pallet runners on the bottom of the containers. Five containers were pushed together on the channel rails to fill the curing chamber, and the door sealed against the front container when closed.

Tines are a major cost factor in container construction, and tine handling is a major labor requirement in a containerized system. To determine the minimum number required, tests were conducted using 4, 5, 6 and 7 tine bars per container. The top and bottom bars were positioned 5 in. (12.7 cm) from the ends, and the intermediate bars were spaced 10, 12, 15 and 20 in. (1 in. = 2.5 cm) respectively.

The tine placement station was organized at the edge of the field, since it was necessary to minimize travel with the tobacco unsupported in the container. A field transporter using the three point hitch lift brought a full container-pallet from the field, and picked up an empty. The tine station operator using a forklift mounted on the rear of a utility size tractor, removed the loaded container from the pallet, inserted the tine bars one at a time (Fig. 6), rotated the container onto its edge (Fig. 7), and placed it on a flatbed truck. He then removed an empty container from the truck with the forklift, and placed it on the pallet in preparation for the next exchange by the field transporter. (The empty containers weighed 340 lb. (154.4 kg), so it was not practical to handle them by hand).

To obtain container weights, and thus evaluate loading variation, a single container was weighed on platform scales prior to placement in the

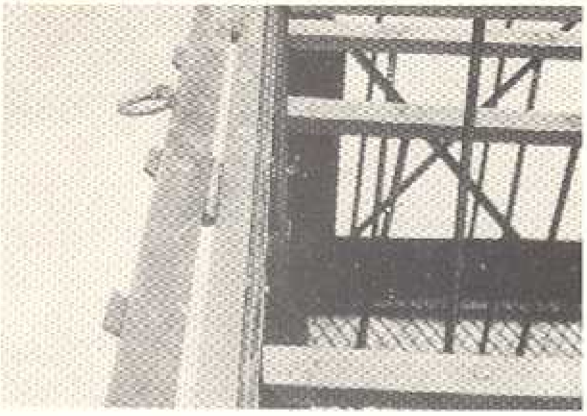

Figure 2. Tine bar sliding in guide.

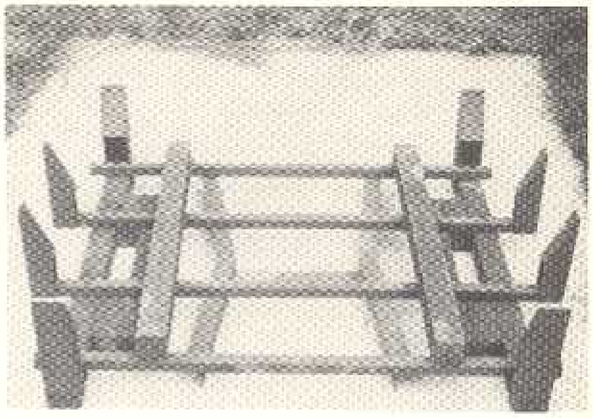

Figure 3. Pallet for field transport of containers.

Figure 4. Three point hitch lift used for field transport.

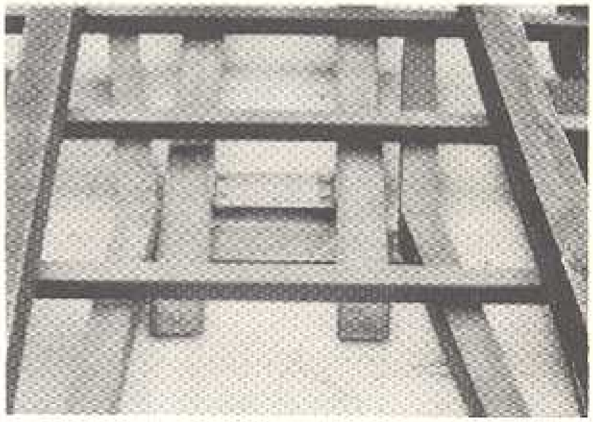

Figure 5. Fork arms locked into place under pallet.

Figure 6. Tine bars being placed in loaded container.

Figure 7. Container rotated onto edge for transport to curing barn.

curing chamber. Comparison of the cured and green weights gave the moisture percentage, and this was used to obtain the green weights from the cured weights for the unweighed containers.

To unload the barn, the containers were removed and put in the same configuration used at the tine placement station. The tine bars were placed directly on a pick-up truck frame for transport back to the field, and the empty containers were loaded on the flat bed truck. Cured leaf was wrapped in burlap sheets for marketing in the conventional manner.

Data Collection

A variable speed drive was installed on the fan-furnace unit (Powell Model 03) used to supply heated air to the plenum [13 x 46 in. (0.32 x 1.17 m)] formed by the foundation walls. To obtain airflow curves for various fan speeds, the plenum was enclosed so that flow was directed through a gate or restriction, and exhausted through 12 in. (0.3 m) section of flow straightener material (Fig. 8) with 0.25 in. (6.2 cm) diameter cores. The gate was manipulated to vary static pressure measured with a manometer. The airflow at the flow straightener was surveyed at 12 points with a thermo-anemometer (Alnor), and the average point velocity was multiplied by plenum area to obtain volume flow.

The center container was instrumented with 108 copper constantan thermocouples to measure temperature distribution during the cure. Three grids (Fig. 9) with six columns of six thermocouples each were spaced in the container, 4 in. (10 cm) from the bottom, in the middle, and 4 in. (10 cm) from the top as the container was hand loaded in the field. In the barn, the thermocouple leads were connected with multipoint plug extension cables to a terminal board in an instrument room adjoining the curing chamber. Here the voltage across a cold junction compensator (OMEGA MODEL CJ)

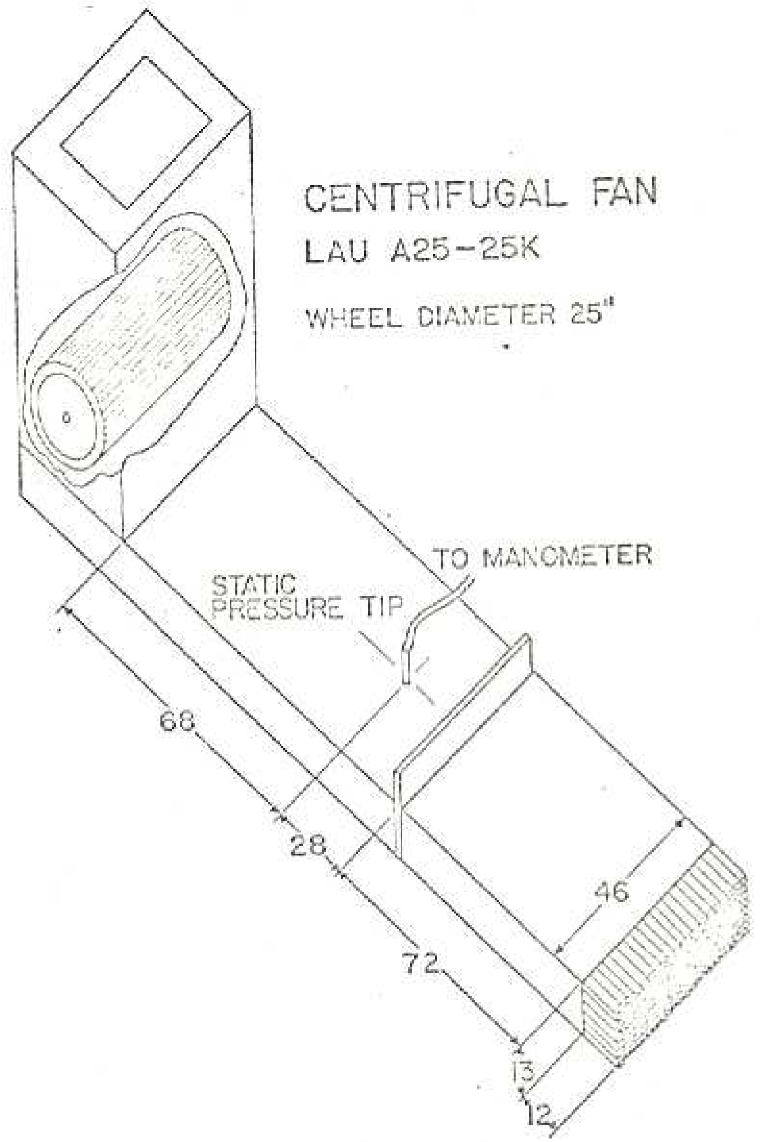

Figure 8. Test arrangement for airflow measurement. [Dimensions in inches (1 in. = 2.54 cm)].

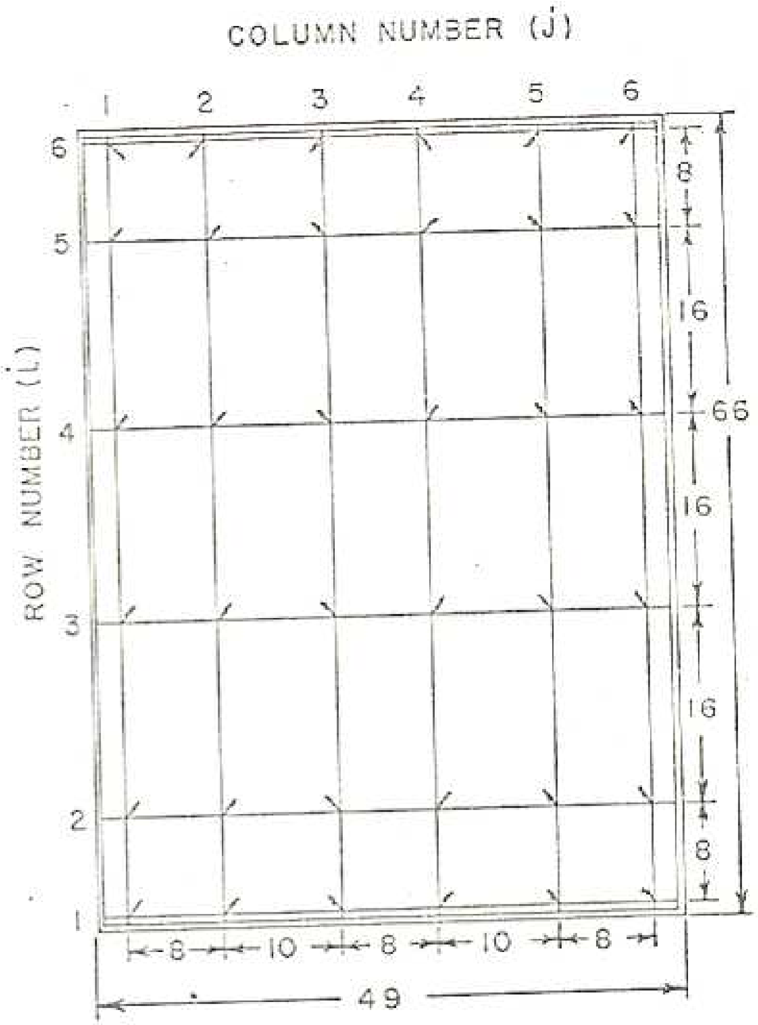

Figure 9. Thermocouple grid for measurement of temperature profile. [Dimensions in inches (1 in. = 2.54 cm)].

was measured with a digital volt meter as individual thermocouples were switched into the circuit by hand.

RESULTS AND DISCUSSION

Very few problems were encountered with the handling system. The containers could be handled empty or loaded with the equipment described. The rear mounted forklift used at the tine placement station was somewhat awkward because of impaired visibility. A front mounted unit would have been more satisfactory.

The pallet and three point hitch lift worked well. The self alignment guides guides were particularly helpful during exchange of empty and full containers on the rear of the primer. It would have been preferable for the primer to lower a loaded container-pallet at the end of the row, and pull out from under it, so that after making a 90° turn, the empty lift would be presented to the tractor backing up to it with an empty container-pallet. However, the primer lift would not lower all the way to ground level; thus, the tractor operator had to drop his empty pallet, remove the full one from the primer, drop it, pick up the empty and place it on the primer, and then pick up the full one for transport to the tine station. A simple modification to the primer lift would eliminate this problem.

One man could easily press the tine bars into position, and the hinged rail remained locked even when the container was rotated completely over on its face. The option of having all the tine bars fixed together in one unit was rejected because it would take two men to handle such a unit, and some type of press would probably be required to force it into the container. Handling was facilitated by having the bars aligned on the pickup truck frame, and the tine placement station organized such that the worker could pick one up and step directly onto the container and put it into position.

Tobacco was cured four times in the containers. Cures 1 and 2 were used to adjust airflow and finalize design of the temperature data collection system, thus data is presented for cures 3 and 4 only. The final harvesting was cured by the farmer in his own barns.

It was determined that 5 tine bars will adequately support the tobacco during curing. When only four were used, some tobacco fell from the front of the container as it was handled.

The weight of tobacco loaded in each container is given in Table 1. The weight of container 4 during cure 3 was 13% above the average, and it was the last to dry. The distribution for cure 4 was slightly improved; container 2 had the major weight deviation having 9.5% less tobacco than the average. All containers appeared to finish drying at approximately the same time during cure 4. From this limited test, it seems that containers field loaded to within ± 10% of the average density can be successfully cured.

Table 1. Container weight distribution.

	Cure 3 (lbs)*		Cure 4 (lbs)	
Container No.	Green	Cured	Green	Cured
1	440	78	600	116
2	480	85	520	100
3	490	87	575	111
4	540	95	580	112
5	440	78	575	111
Avg.	478	85	570	110

* 1 lb = 0.4536 kg

The minimum fan speed obtainable with the variable speed drive, 185 rpm, was used for cure 3. When it was observed that the curing time was being unacceptably lengthened, the speed was increased at 144 hours to 250 rpm, and held at this point until stem drying was completed. For cure 4 the fan speed was increased to 250 rpm at 62 hours. This reduced the total leaf and stem drying time by 14 hours, and thus reduced the total cure time to 148 hours, a normal 6 day cure.

A static pressure of approximately 0.05 in. (0.13 cm) water was measured in the plenum under the middle container during reordering which is the time of maximum airflow through the tobacco. Referencing the airflow curves (Fig. 10) the maximum flow at 185 rpm was 2850 CFM (77 m^3/min), or, expressed in terms of exposed tobacco cross section 50 CFM/ft^2 (15 $m^3/min/m^2$). At 250 rpm the maximum flow was 4400 CFM (119 m^3/min), or, 75 CFM/ft^2 (22.5 $m^3/min/m^2$). [This compares with 74 CFM/ft^2 (22.2 $m^3/min/m^2$) obtained from manufacturer's data for a commercial three-tier bulk barn (Powell Model 88).]

Containerized curing represents a slightly different material distribution as compared to curing in bulk racks. With bulk racks there is some opportunity for redistribution of airflow between the tiers. The thermocouple grids permitted a study of the drying front movement through the containers.

The average temperature at the top T_p and bottom T_b, of the test (No. 3) container is, in general,

$$T_p = \sum_{j=1}^{6} \sum_{k=1}^{3} t_{ijk}/18 \qquad i = 6 \tag{1}$$

$$T_b = \sum_{j=1}^{6} \sum_{k=1}^{3} t_{ijk}/18 \qquad i = 1 \tag{2}$$

where

t_{ijk} is the thermocouple reading corresponding to a given row

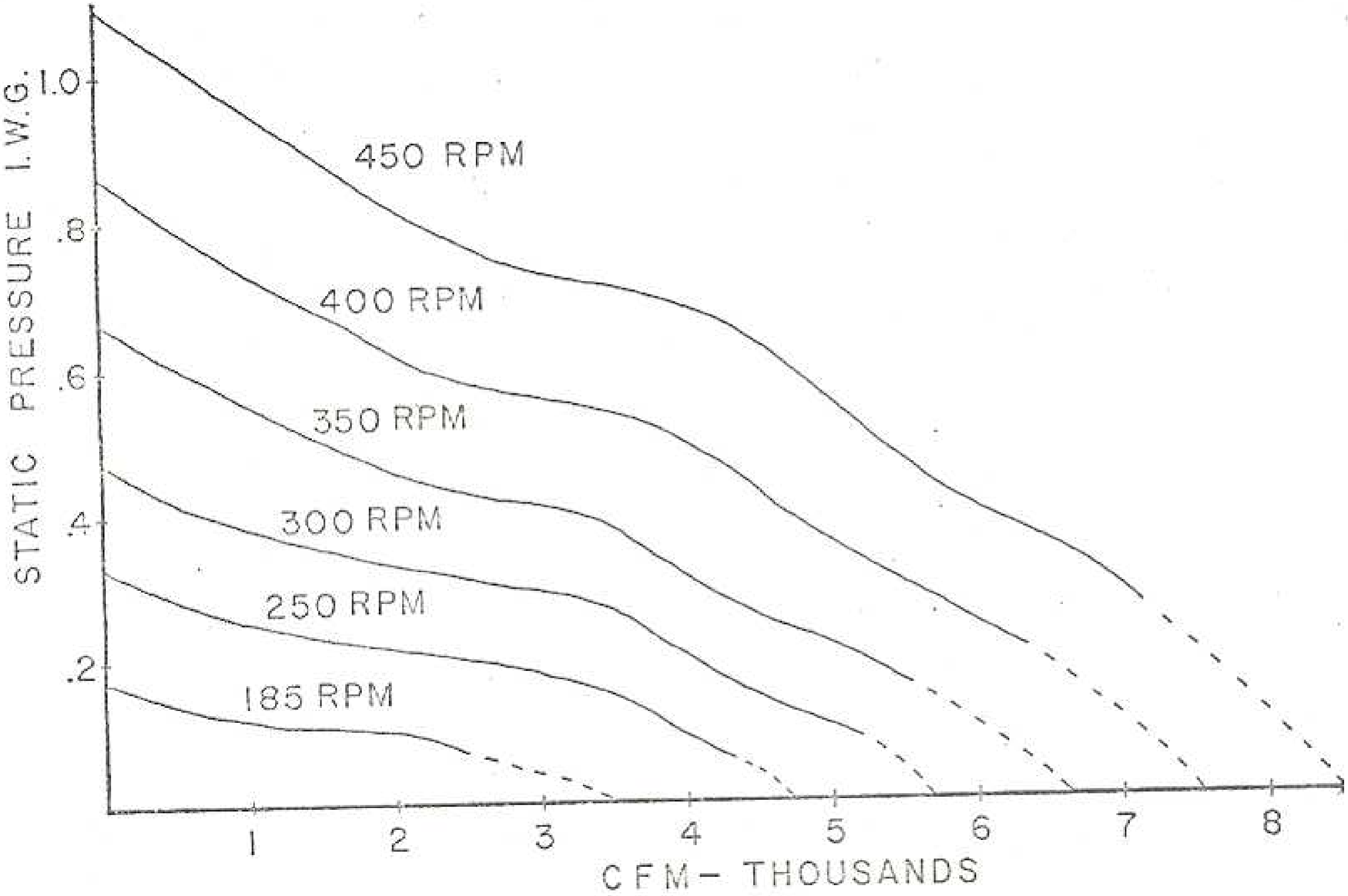

Figure 10. Airflow curves for the curing chamber.

and column location, and the third subscript, k, refers to the grid number reading from front to rear (from the door to the furnace) in the container. The temperatures in columns 1 and 6 were found to be slightly higher due to more rapid movement of the front along the walls. To obtain a more representative average top and bottom temperature for the mass, these columns were eliminated. For example, in considering the averages for grid 2 alone

$$T_{p2} = \sum_{j=2}^{5} t_{ijk}/4 \qquad \begin{matrix} i = 6 \\ k = 2 \end{matrix} \tag{3}$$

$$T_{b2} = \sum_{j=2}^{5} t_{ijk}/4 \qquad \begin{matrix} i = 1 \\ k = 2 \end{matrix} \tag{4}$$

The slow drying rate during cure 3 is revealed by plots of T_{b2} and T_{p2} vesrus time for cure 3 (Fig. 11) and cure 4 (Fig. 12). Note that the return air temperature is greater than T_{p2} until leaf drying is completed, indicating a wet bulb depression between the undried leaf and the return air. The thermocouple temperature between two undried leaves is essentially a wet bulb temperature.

In Table 2 the temperature difference ($\Delta T = T_{b2} - T_{p2}$) during cure 4 is compared with that found by Sykes (14) for two-tier bulk curing. The magnitude of the container ΔT is greater because of the greater curing depth; however, the distribution with time is quite similar.

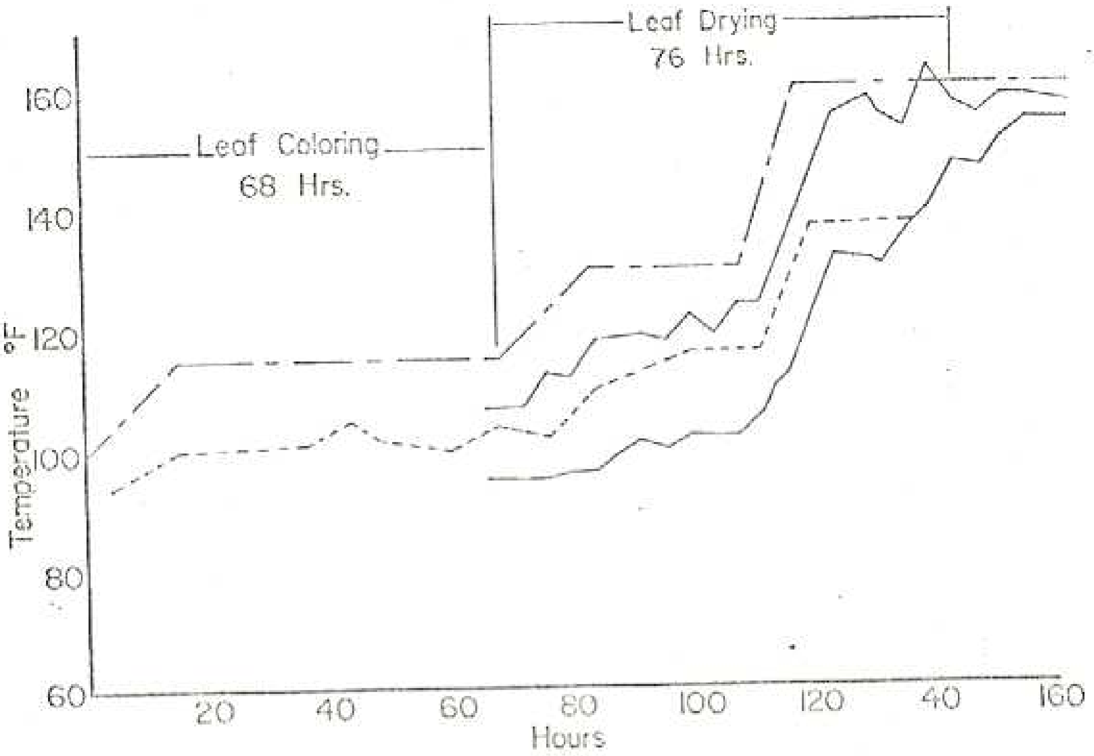

Figure 11. Comparison of bottom (top solid curve) and top (bottom solid curve) average temperature in grid 2 with return air temperature (dotted curve) and the thermostat setting (dot-dash) during cure 3.

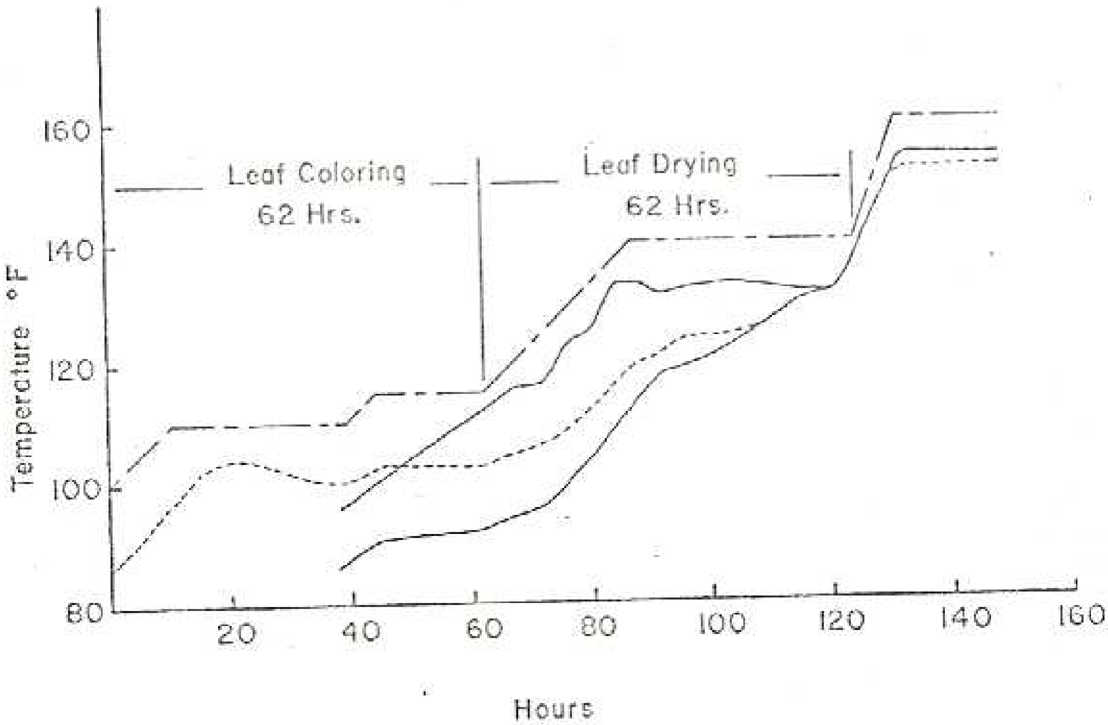

Figure 12. Comparison of bottom (top solid curve) and top (bottom solid curve) average temperature in grid 2 with return air temperature (dotted curve) and the thermostat setting (dot-dash curve) during cure 4.

Table 2. Comparison of top-bottom temperature differences for two-tier bulk and containerized curing.

	Temperature Difference, ΔT, °F*	
Hour	Two-tier Bulk Curing[a]	Containerized Curing
40	5	10
44	5.5	10
48	8	12
52	10	14
56	12	17
60	12	19
64	15	20
68	12	21
72	11	20
76	13	23
80	17	21
84	18	24
88	13	19
92	9	13
96	5	13
100	5.5	12
104	3	10
108	1	6
112	1	4
116	-	1
120	-	-

* °C = 5°F/9

[a] Table 7.1 Temperature differentials for cure number 3 (values in °F), Sykes (14).

During field loading and handling the tobacco at the bottom (in the back in the curing position) was compressed to a greater density. This effect was not expected to be very great for the hand loaded test container; however, it was measurable. Comparison of the top and bottom average temperatures from equations (3) and (4) for the three grids during cure 3 (Fig. 13) and cure 4 (Fig. 14) shows that the front tobacco tended to dry before the center, which dried slightly before the back tobacco. This phenomenon was accentuated by the slow drying rate in cure 3, and, was also observed in cure 4. [Note particularly the differences between grids 1 and 2

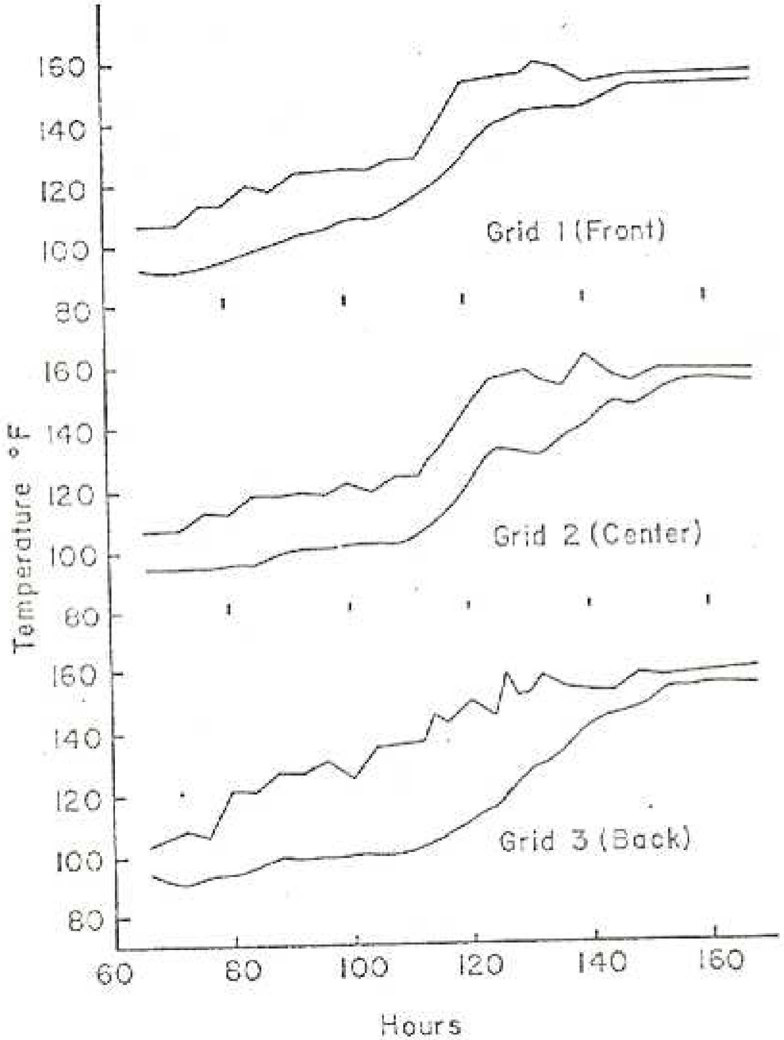

Figure 13. Comparison of bottom (top curve) and top (bottom curve) average temperature during cure 3.

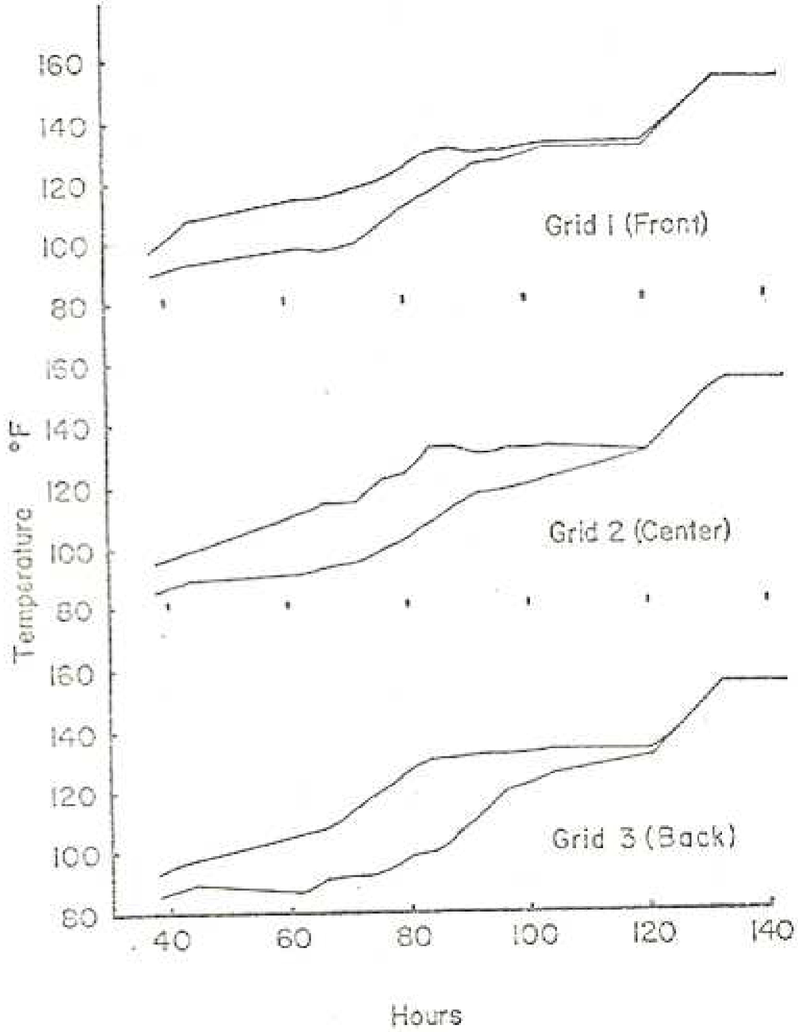

Figure 14. Comparison of bottom (top curve) and top (bottom curve) average temperature during cure 4.

(Fig. 14).] It was observed that the harvester loaded containers dried generally from front to rear, and the section 6 - 8 in. (15 - 20 cm) from the rear was the last to dry.

In cure 2 it was observed that tobacco along the container side walls dried first. Prior to cure 3, a 4 in. (10.2 cm) baffle was placed in the plenum end of the container to direct airflow away from all four edges toward the center. These baffles, improved drying and wider baffles should be evaluated in future work to optimize the design.

Movement of the drying front up through the test container during curve 4 was revealed by plotting average temperature for.each row of thermocouples in grid 2 versus time (Fig. 15). The time of intersection of the row temperature curve (denoted by the circled numbers, Fig. 15) with the composite temperature curve for the rows beneath it, was taken as the time the drying front had reached that level. Above the row 2 level the front moved linearly with time through the container.

In cures 3 and 4 all the tobacco dried, and no wet areas resulting from nonuniform loading were found. No scalded tobacco resulted from the slow drying rate in cure 3. The only damaged or discolored tobacco was that which hung down from the end of the container into the plenum. This tobacco was exposed directly to the heated air, and began to dry before the enzymatic activity associated with leaf coloring was completed. Wetted burlap bags were placed in the plenum in an attempt to keep the humidity up, but this was not effective.

SUMMARY AND CONCLUSIONS

Tobacco was successfully cured in 68.7 ft^3 (1.85 m^3) containers loaded to a density of 8.4 lb/ft^3 (141 kg/m^3) with a conventional automatic

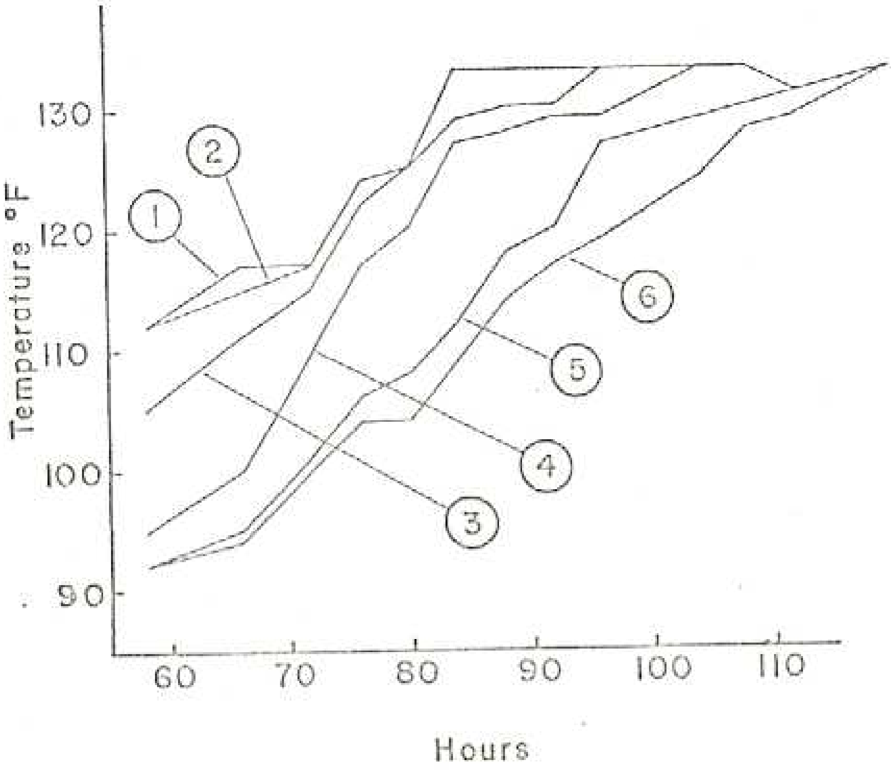

Figure 15. Average row temperature in grid 2 during cure 4. (Circled numbers refer to grid rows).

tobacco primer. Five tine bars with 0.5 in. (1.3 cm) O.D. tubing spaced 9 in. (23 cm) apart were used to support the tobacco. The containers were handled with tractor mounted forklift equipment with a 1500 lb. (680 kg) lift capacity.

Measurement of temperature distribution throughout the containers revealed the expected drying front movement from bottom to top. It was also found that the container front (top in the loading position) dried before the back (bottom in the loading position). This was due to packing during field travel which caused a positive density gradient from top to bottom. Baffles were placed in the plenum end of the container to alleviate this problem.

Two air capacities, 50 CFM/ft^2 (15 m^3/min/m^2) and 75 CFM/ft^2 (22.5 m^3/min/m^2) were evaluated. The lower flow was sufficient to cure the tobacco; however, the time required was greater than the normal 6 day cure. The higher flow was sufficient for a 6 day curing cycle.

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