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FORCED-AIR COOLING OF STRAWBERRIES IN REUSABLE PLASTIC CONTAINERS

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Abstract. **Cooling data of strawberries packed in clamshell containers and placed in reusable plastic containers (RPC's) are presented. These data include the cooling times at different locations of the clamshells within each RPC, at different locations of the RPC within the stack and the effect of blocking off some of the open by-pass areas in the RPC to force more air through the fruit in the clamshells. The cooling tests were conducted at a commercial cooling facility.**

For the last two decades, Europe has been the leader in the use of reusable plastic containers (RPC's) (Chonhenchob and Singh, 2003). Wal-Mart stores in North America is leading the change from the traditional corrugated fiberboard trays to RPC's and it is expected that over 150 million RPC's will be needed to serve the North American market for fruits and vegetables (Chonhenchob and Singh, 2003).

Strawberries sent to the consumer market are typically packed in individual containers and these individual containers are then placed on trays for precooling, temporary storage, and transportation (Anderson et al., 2003; Talbot et al., 1995; Thompson and Knutson, 1997). Different kinds of material, sizes and shapes used for individual containers have been introduced over time. The thermoformed plastic with a clamshell design, tapered side, hinged lid and less venting is now a popular packaging for strawberries (Anderson et al., 2003; Talbot, et al., 1995). This material and design lead to increased protection against injury during the postharvest handling process (Anderson et al., 2003), but there is still very little published information on precooling with the use of these containers especially in combination with RPC's. Previous tests conducted by Talbot et al. (1995), Emond et al. (1996), and Anderson et al. (2003) all pointed out that the containers' design and its orientation inside the corrugated fiber board tray have a significant effect on the precooling time of the strawberries.

In addition to the increased cooling cost, delay in cooling of strawberries for just 6 h at 30 °C resulted in fruit that had significant decrease in firmness, soluble solid content, sugars and ascorbic acid levels as well as less attractive appearance (Nunes et al., 1995). Thus rapid and uniform cooling of strawberries to their optimal temperature will not only extend their postharvest life and preserve their nutritive values, but will also allow more throughputs at a cooling facility.

The objectives of this study were (a) to study the effect of the headspace above the clamshell containers in the RPC's and the empty spaces between clamshells on cooling rates and (b) to study the variability of the cooling times for the different clamshells at different locations downstream from the entrance of the cooling air.

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Materials and Methods

A portable forced-air cooling unit was designed and constructed. The forced-air cooling unit was designed to have the same footprint of a typical pallet, 1.016 × 1.220 m. The unit can accommodate five layers of 0.610 × 0.406 × 0.127 m reusable plastic container (RPC) tray. The unit was installed with a valve and a flow meter (Annubar, Dieterich Standard Corp, Wallingford, Conn.) to regulate and measure the airflow rate as shown in Fig. 1.

Strawberry cooling tests were done at a commercial forced-air cooling facility. Strawberries of the variety "Strawberry Festival" were packed in 0.454 kg clamshell containers and placed in RPC's. The dimensions of the RPC are given in Table 1. Nine clamshell containers can fit in 1 RPC and 5 RPC's can fit in a layer on a pallet, thus the term "5-down configuration".

Five layers of RPC trays were stacked inside the forced-air cooling unit with the three middle layers containing strawberries (Fig. 2). The bottom and the topmost layers of RPC's were filled with styrofoam and covered with a plastic tarpaulin to block off the cooling air and force the air through the three middle layers. The middle most layer was instrumented with thermocouples. Every clamshell in this layer had at least

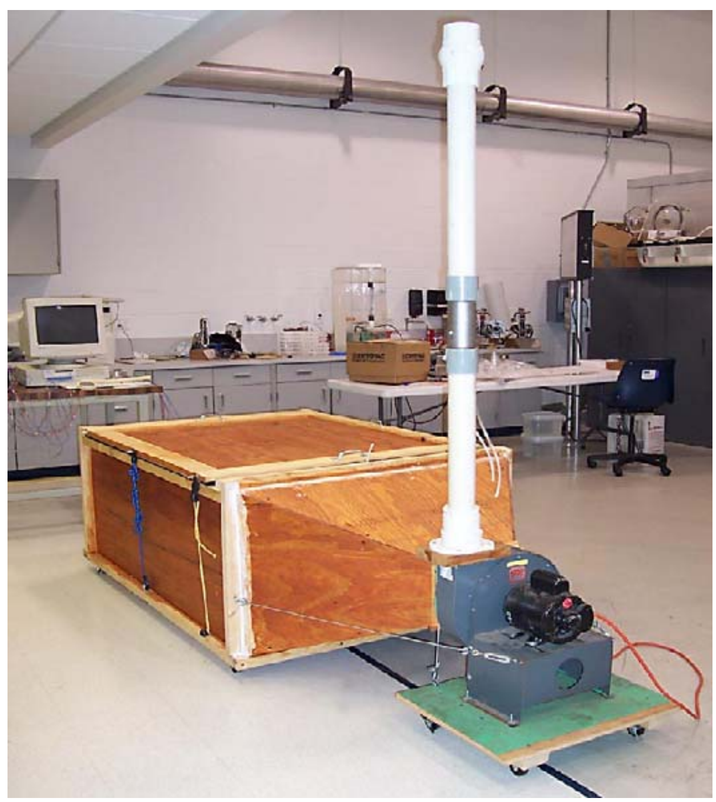

Fig. 1. The forced-air cooling unit installed with blower and annubar.

Table 1. Specifications of the GP 6411 Reusable Plastic Container (RPC) tray.

Outside dimensions cm			Inside dimensions cm			Collapsed Height cm	Return ratio	Capacity liters	Weight kg
L	W	H	L	W	H				
60.00	40.00	12.70	57.46	37.46	11.02	3.56	3.6 to 1	24.04	1.47

Source: IPL, Inc., Smartcrate.

one thermocouple inserted approximately in the center of the strawberry from its calyx. There were a total of 62 Type T, 30-gauge thermocouples used.

Once the blower was turned on, the temperature of the strawberries and the air entering and exiting the forced air cooling unit were monitored. The temperatures were recorded every 60 s using a data logger (CR10, Campbell Scientific, Inc. Logan, Utah), equipped with two multiplexers (AM 416 Relay Multiplexer, Campbell Scientific, Inc. Logan, Utah) to handle 66 thermocouples.

The valve attached to the annubar flow meter was adjusted to have a uniform air flow rate for all the treatments and throughout the cooling process. All pressure measurements were done with a handheld digital manometer (Dwyer Instruments, Inc., Series 475, Michigan City, Ind.).

The determination of the ⅞th cooling time and the calculation of the cooling coefficient were done for each treatment. The cooling coefficient is the slope of the line from a plot of the natural log of the temperature ratio against time (Anderson et al., 2003; Guillou, 1958). The cooling coefficient has a unit of inverse time and the steeper the slope means faster cooling time. The ⅞th cooling time was used because it is the typical practice in the commercial cooling industry. The calculation of the ⅞th cooling time assumes constant temperature throughout the cooling process. During the actual cooling tests, the air temperature in the commercial precooler was not constant; the average precooler air temperature during each cooling test was used to calculate the ⅞th cooling time.

There were three treatments as shown in Fig. 3 with three replications each in this study: 1) Treatment 1 (Control): the clamshell containers were placed in RPC's with no modifications, 2) Treatment 2: the headspace between the top of the clamshells and the bottom of the RPC directly above was

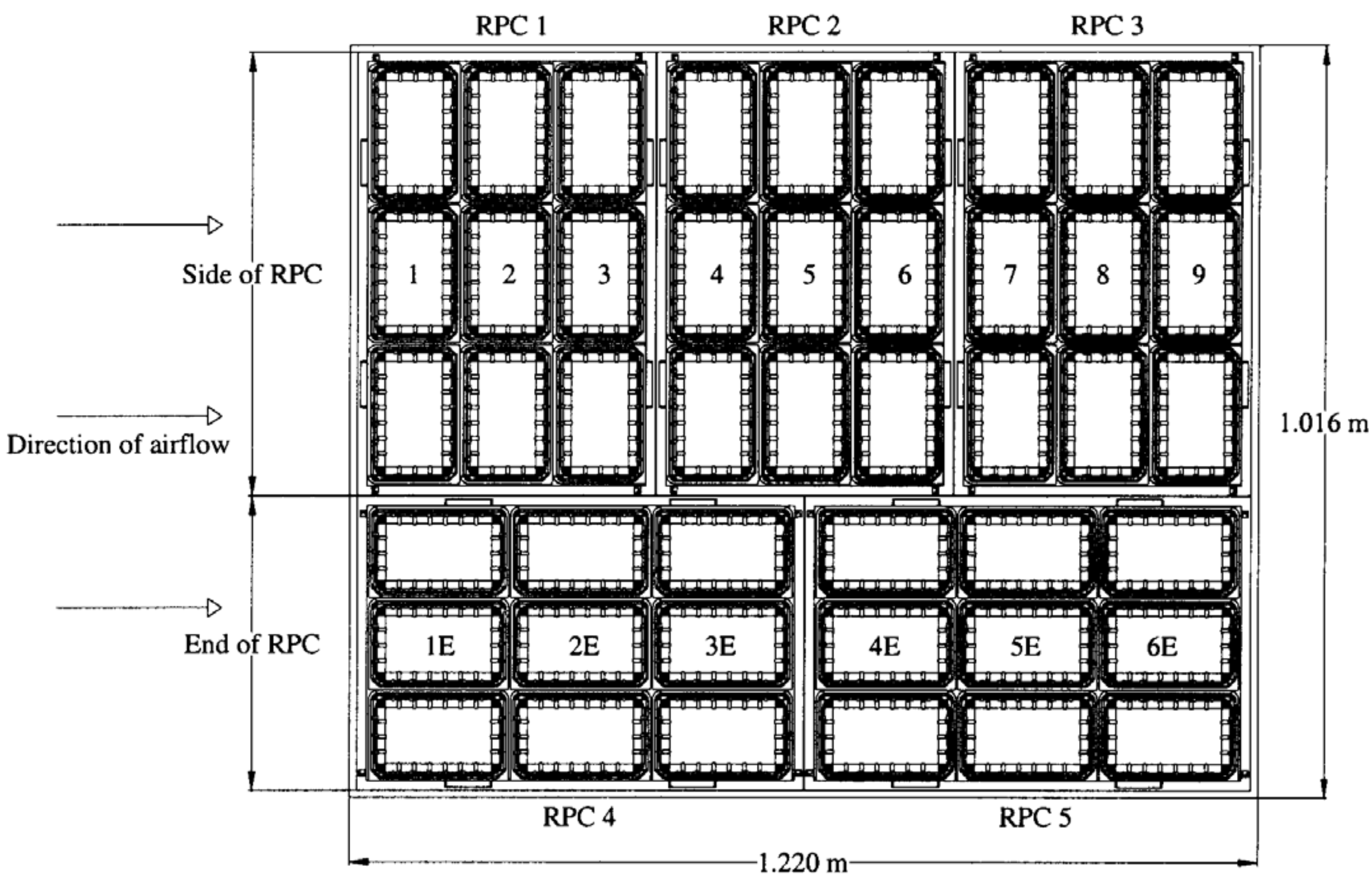

Fig. 2. Top view of pallet with a "5–down configuration". There are 5 RPC's with 9 clamshells each.

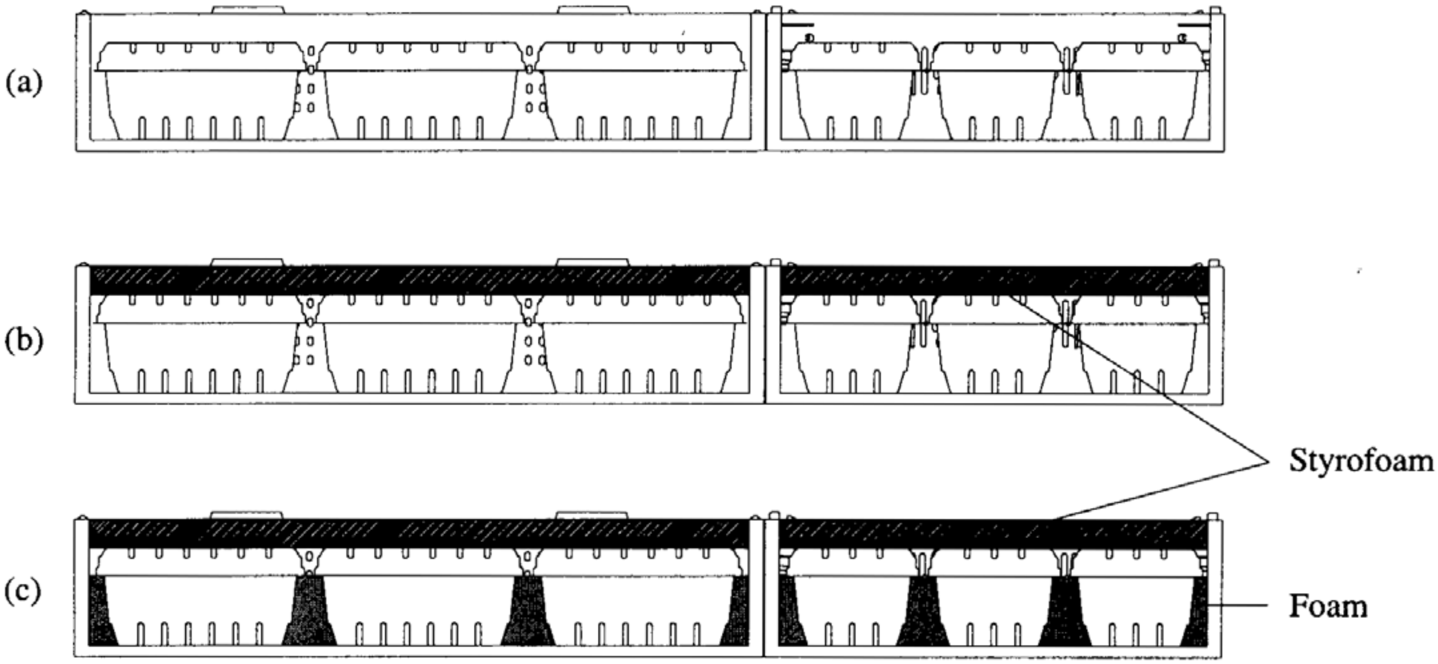

Fig. 3. Cross section of the three different treatments used in the cooling test: (a) standard configuration (there is an air gap above the clamshell), (b) clamshell containers with 2.54 cm thick styrofoam at the top of the clamshells, and (c) clamshell containers with 2.54 cm thick styrofoam at the top of the clamshells and the spaces between clamshell containers and the sides of the RPC trays covered with foam.

blocked off with a 2.54 cm thick styrofoam, and 3) Treatment 3: all the by-pass areas (headspace and between the sides of the clamshells) were blocked off.

Results and Discussion

Objective 1: Effect of blocking the by-pass areas in the RPC's.

The clamshells had an average weight of 0.537 kg and contained 23 strawberries on average. The ⅞th cooling time and the cooling coefficient were calculated for each clamshell and averaged for each treatment. The ⅞th cooling times, cooling coefficients, pressure drops, and airflow rates are shown in Table 2. Blocking the headspace decreased the ⅞th cooling time from 82.5 min to 76.3 min, but blocking all the by-pass areas resulted in a very large decrease in cooling time, to 65.0 min. However, the pressure drop also increased dramatically.

Using Dunnet's method of statistical analysis, the difference between treatments 1 and 2 is not significant at 5% level. For treatment 3, the test results were statistically significant at 5% level. It means that at 5% significance level, the data provide a sufficient evidence to conclude that blocking off all the by-pass areas in the RPC's would lower the cooling time as shown in Table 2.

Objective 2: Changes in cooling times as a function of the distance downstream and location of the clamshell container in each RPC.

Tables 3a and 3b show the ⅞th cooling times of the different clamshell containers as a function of the distance downstream and location within the RPC.

Table 2. The ⅞th cooling times and cooling coefficients of every treament.

Treatment	⅞th cooling time (min)	Cooling coefficient (min-1)	Pressure drop (Pa)	Airflow rate (l s^{-1} kg^{-1})
1	82.5	-0.0202	17.44	1.71-1.78
2	76.3	-0.0241	44.84	1.71-1.79
3	65.0	-0.0316	191.81	1.75-1.83

Table 3a. ⅞th cooling times as a function of the location of the clamshell container inside the RPC and in the forced-air cooling unit. Side of RPC.

	⅞th cooling time (min)								
Treatment	Clam 1	Clam. 2	Clam. 3	Clam. 4	Clam. 5	Clam. 6	Clam. 7	Clam. 8	Clam. 9
1	66.5	88.0	72.0	83.5	98.0	83.5	90.5	101	84.5
2	54.0	75.0	74.0	76.3	80.7	88.7	77.3	92.7	89.7
3	39.0	53.3	56.0	60.3	65.7	73.7	71.30	82.0	81.3

Table 3b. ⅞th cooling times as a function of the location of the clamshell container inside the RPC and in the forced-air cooling unit. End of RPC.

Treatment	⅞th cooling time (min)					
	Clam 1E	Clam. 2E	Clam. 3E	Clam. 4E	Clam. 5E	Clam. 6E
1	75.0	79.0	97	82	100.0	83.0
2	59.3	79.0	78.7	72.0	84.7	82.7
3	41.7	60.0	73.3	68.0	77.3	79.0

Table 4. ⅞th cooling times as a function of the location of the RPC in the forced-air cooling unit. Refer to Fig. 2.

Treatment	⅞th cooling time (min)				
	Side of RPC			End of RPC	
	RCP 1	RCP 2	RCP 3	RCP 4	RCP 5
1	75.5	88.3	91.8	83.7	88.3
2	67.7	81.9	86.8	72.3	79.8
3	49.4	66.7	78.2	58.3	74.8

The results showed that for treatments 1 and 2, most of the clamshell containers located in the middle part of the RPC had longer cooling times as compared to one or two clamshell containers located farther from them. It was also observed that clamshell 9 which was located at the end and exposed to the exiting air had faster cooling as compared to the clamshell container preceding it. Clamshell containers 4 and 7 were located at the entrance of the RPC as compared to the clamshell containers 2 and 5 which were located at the middle part of the RPC. Air passing through the by-pass areas may have an effect on the air going though the second and third RPC's and lowering to some degree the air entering the clamshell containers in those RPC's, especially the clamshell containers located at the entrance of the RPC.

The results showed that having the same boundary conditions and locations inside the RPC, the cooling rate of strawberries increased as it goes farther from the entrance of the entering cold air.

For treatment 3, the cooling times of the clamshell containers tend to increase with distance downstream. Since all the by-pass areas where blocked off for this treatment, all the heat released by the fruit upstream passes through all the fruit downstream.

Looking at the data from Tables 3a and 3b and considering the ⅞th cooling time of each clamshell container as a function of the distance downstream to the entering cold air, the third treatment had the fastest cooling time as compared to the two treatments.

Considering the average cooling times of clamshell containers per RPC's, Table 4 shows the averaged ⅞th the cooling time for every RPC. The results showed that the cooling time was increased as the RPC was placed farther away from the entrance of the entering cold air.

The results showed that the empty spaces between clamshell containers in the RPC's had a significant effect on the cooling time of the strawberries. Location of clamshell containers inside the RPC and the location of the RPC's inside a forced-air cooling unit can also affect the cooling time of strawberries. Therefore, clamshell containers and RPC trays should be designed together to ensure efficient cooling.

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