Performance of FARM EGG COOLERS

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Technical Bulletin T-93
January, 1962

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The mandatory egg grading law which became effective in Oklahoma, November 1, 1957, created interest in the design and operating requirements for on-the-farm cooling and holding of eggs for periods of one week or less. This bulletin reports results of a four-year study of the design and operating requirements for such coolers. All of the experimental work was done at Stillwater, Oklahoma. The research was begun in 1955 and completed in 1959.

The cooler performance factors that were evaluated included: (1) Effects on commercial grade of eggs, (2) effects on egg weight loss, (3) effects on egg cooling rate, (4) energy use as affected by design and management conditions, and (5) performance of milk can coolers used for cooling eggs.

COMMERCIAL GRADE OF EGGS

The interior quality of warm eggs deteriorates rapidly. Experiments and practical experience have established that it is necessary to cool newly-laid eggs to a temperature of 55° to 60° F. as soon after laying as possible, in order to maintain quality. This temperature must be maintained for short-term (one week or less) on-the-farm holding until the eggs are marketed. Such treatment is now mandatory for eggs that are marketed by commercial egg producers in Oklahoma.

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Research reported herein was done under Oklahoma Agricultural Experiment Station Project 1001.

Methods

An experiment was conducted in 1956 to evaluate the effects of refrigerated, compared to non-refrigerated, egg holding environment on egg quality. The commercial grade of the eggs when marketed was used as the quality index. Grading was done by a licensed egg grader to establish the commercial grade for the buyer who priced the eggs according to grade.

The eggs receiving the refrigerated treatment were placed in insulated, mechanically refrigerated egg cooling and holding units. Temperatures in the units varied from 58° F. to 61° F., and relative humidities were 55 to 70 percent. The average temperature in the room used to hold the non-refrigerated eggs was 91° F.

A total of 41,759 dozen eggs, produced on the University Poultry Farm, were used in the experiment. The eggs were placed in either refrigerated (34,002 dozen) or non-refrigerated (7,757 dozen) storage, where they were held for weekly marketing.

Results

The results of this experiment are summarized in Table 1. Eggs sold from the non-refrigerated storage were severely degraded during the hot months of July and August.

TABLE 1.—Effects of Season of the Year and Refrigerated Storage on Commercial Grade of Eggs

Commercial Grade	One-Year Average		Hot-Weather Average (May Through August)	
	Refrigerated	Non-Refrigerated	Refrigerated	Non-Refrigerated
	(percent)			
Grade A	91.05	80.19	84.46	63.02
Grade B	5.04	8.20	8.61	13.08
Grade C	3.91	11.61	6.93	23.90
Totals	**100.00**	**100.00**	**100.00**	**100.00**

The computed annual monetary advantage in favor of refrigerated storage was $324.45 for 41,759 dozen eggs, or approximately 78/100 of a cent per dozen. This computation was based on 38 cents per dozen for Grade A eggs, 35 cents for Grade B, and 30 cents for Grade C. It should be noted that this was an average yearly figure. The per dozen monetary advantage to refrigerated storage would be greater if computed for only the hot weather months.

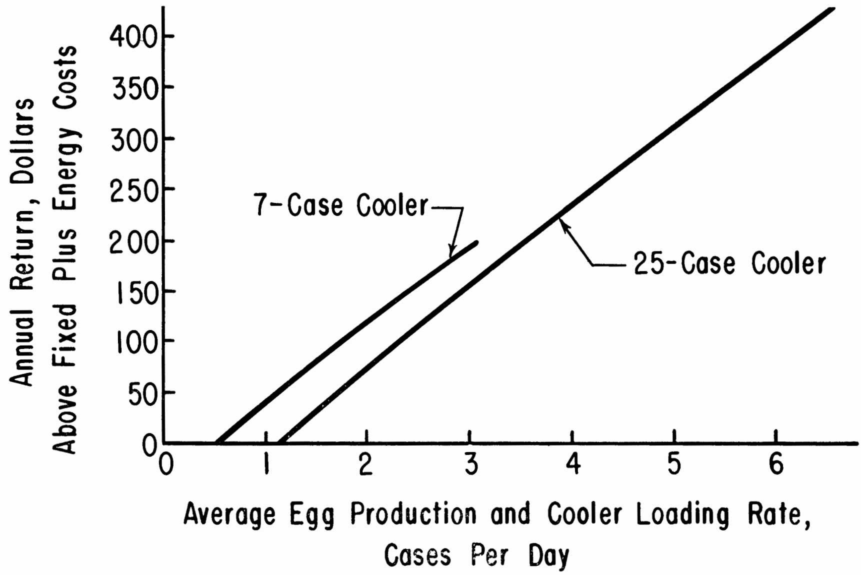

Figure 1. Annual returns above fixed plus energy costs from farm egg cooler.

Predictions for returns from use of on-the-farm egg sales above fixed plus operating costs were made for a 7 case and a 25 case cooler. The results are graphed in Figure 1. These results are based on observed energy use by the coolers, and on the following additional conditions: (1) Yearly average price differential of 78/100 of a cent per dozen in favor of eggs held in refrigerated compared to non-refrigerated storage, (2) yearly average outside minus inside temperature difference of 10 Fahrenheit degrees for the coolers, (3) egg weight of 1.5 pounds per dozen, (4) fixed costs (interest, repairs and maintenance, depreciation) of $36.07 per year for the 7 case cooler, and $71.50 per year for the 25 case cooler, and (5) energy costs of 1½ cents per kilowatt hour.

Figure 1 shows that for maximum profit, egg coolers should be loaded to maximum capacity; and coolers, when filled to maximum capacity, should be no larger than needed to accommodate all the eggs. The frequency of marketing is a principle factor in cooler size requirement.

EGG WEIGHT LOSS

Methods

An experiment was conducted during the summer of 1958 on the effect of three egg cooler humidity levels on weight loss during the holding period. The experiment was also designed to test the effect of sprayed-on sealant on weight loss reduction, and the effect of type of container on weight loss.

The experimental coolers included a 25 case walk-in type cooling cabinet*, and two milk can coolers that had been modified for cooling and holding eggs. One of the can coolers was the ice-bank type with the cold evaporator coils encircling the space in the cooler. The inside dimensions of this can cooler were 33¾ in. by 79¾ in. by 25½ in. deep.

Inside dimensions for the second can cooler were 32½ in. by 55½ in. by 26½ in. deep. This cooler had an immersion type evaporator coil with a 1/5 hp. stirring motor and blade for forced circulation of water over the coil. In order to obtain adequate cooling effect from the immersion coil, it was necessary to install a 14-inch diameter water-filled drum to contain the coil. A small circulating fan was used to blow air against the drum to increase heat transfer from the drum to the air.

A different humidity level was maintained in each cooler. An average relative humidity of 89 percent and dry bulb temperature of 56° F. were maintained in the smaller can cooler. The humidity was maintained by a commercial humidification device, the essential component of which was a spinner blade that flung very small drops of mist into the cooled space. An average relative humidity of 68 percent and dry-bulb temperature of 52° F. were maintained in the larger can cooler. This humidity level prevailed with no control other than the temperature of the evaporator coils. Wooden pallets were placed on the floor of the cooler to hold the egg cases and baskets above the condensate which collected in the bottom of the cooler chamber. An average relative humidity of 47 percent and dry-bulb temperature of 52° F. were maintained in the walk-in type cooler. In order to maintain this low humidity, it was necessary to install a silica gel tray with forced air circulation over it, and to continuously drain away the condensate from the evaporator coils.

*This was the same cabinet in use in the "Cooler Energy Use" experiment. Description of the cabinet is given on page 14.

TABLE 2.—Egg Weight Loss Rate as a Percentage of Original Egg Weight

Humidity*	Container	Sealant	Weight Loss (gm./24 hr.)	Avg. Egg Weight (gm.)	Percent of Weight Loss (per 24 hr.)	Percent of Weight Loss (per week)
Low	Case	Sprayed	0.076918	62.8	0.122	0 854
		None	0.073939	59.5	0.124	0.868
	Basket	Sprayed	0.075323	60.2	0.125	0 875
		None	0.082364	58.2	0.141	0.987
Medium	Case	Sprayed	0.023124	59.6	0.039	0.273
		None	0.033574	60.9	0.055	0.385
	Basket	Sprayed	0.037820	59.6	0 064	0.448
		None	0.048099	59.0	0.081	0.567
High	Case	Sprayed	0.010886	59.6	0.018	0.126
		None	0.023485	61.5	0.038	0.266
	Basket	Sprayed	0.023040	62.7	0.037	0.259
		None	0.031606	57.9	0.055	0.385

* Low=47 percent; Medium=68 percent; High=89 percent.

Other storage variables in addition to the three humidity levels included a proprietary oil and wax spray applied to half the eggs in each lot, and variations in type of egg containers. The two container types compared were a standard cardboard egg case and a wire basket.

Thirty newly-laid eggs were randomly assigned to each of the twelve treatment combinations, for a total of 360 eggs in the experiment.

Each egg was weighed each morning over a four-week period. The daily weights were used to determine a linear regression coefficient of weight loss on elapsed time in storage. This coefficient had the dimensions of weight loss rate in grams per 24 hours.

Results

The average values are shown in Table 2. The regression coefficients were tested by covariance analysis, with results as shown in Table 3. Table 4 shows the results of applying multiple range analysis to the regression coefficients.

TABLE 3.—Analysis of Variance of Egg Weight Loss as Affected by Cool Storage Variables

Treatment Variables	Degrees of Freedom	Mean Square $\times 10^{-4}$	Variance Ratio	Significance Level
Sprayed vs. unsprayed	1	0.8466	1.34	$p = 0.27$
Cased vs. basket	1	2.6438	4.19	$p = 0.04$
Humidity level	2	32.7487	52.00	$p = 0.0005$
Spray $\times$ container	1	0.0570	<1	----------
Spray $\times$ humidity level	2	0.7992	1.27	$p = 0.28$
Container $\times$ humidity level	2	0.3175	<1	----------
Container $\times$ spray $\times$ humidity level	2	0.0125	<1	----------
Egg differences ("Error")	318	0.6298	------	----------

TABLE 4.—Multiple Range Test of Egg Weight Loss Rate Coefficients, for Differences at 5% Confidence Level

Computed Regression Coefficients			Treatment Combination		
Rank	Weight Loss (gm./24 hrs.)	Grouping Range	Humidity Level	Container Type	Sealant
1	0.010886		High	Case	Sprayed
2	0.023040		High	Basket	Sprayed
3	0.023124		Medium	Case	Sprayed
4	0.023485		High	Case	None
5	0.031606		High	Basket	None
6	0.033574		Medium	Case	None
7	0.037820		Medium	Basket	Sprayed
8	0.048099		Medium	Basket	None
9	0.073939		Low	Case	None
10	0.075323		Low	Basket	None
11	0.076918		Low	Case	Sprayed
12	0.082364		Low	Basket	Sprayed

EGG COOLING RATE

Rapid cooling of freshly gathered eggs is desirable to maintain the freshly laid quality. On farms, the usual practice is to gather the eggs into standard wire egg baskets. The baskets of eggs are placed in a suitable position in the egg cooling cabinet until the eggs are cooled, after which they are packed in cartons or cases.

Methods

An experiment was conducted to investigate the cooling rate of eggs in standard wire baskets as affected by: (1) Position of the egg in the basket, and (2) position of the basket with respect to the cool air discharged from the cooling unit. The two egg positions included the center of, and the periphery of, the basket.

The egg baskets were placed on a slatted shelf 16 inches above the floor, and positioned with respect to the cool air discharge as shown in Figure 2.

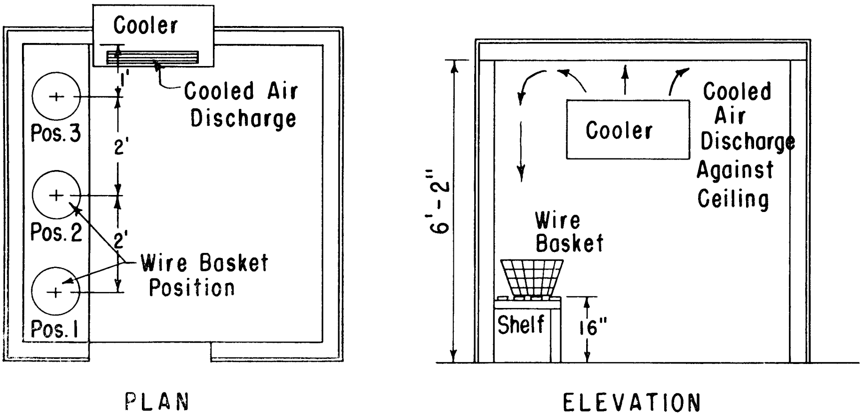

Figure 2. Basket positions for experiments on cooling rates of eggs.

Three eggs were used in each of the two positions in each basket. Egg surface temperatures were continuously recorded on a multipoint recorder, with a thermocouple taped to the surface of each egg. Egg surface temperatures were recorded for three replicated runs of four hours duration each. Air temperatures in the cooler cabinet were continuously recorded by a thermograph.

The cooler cabinet was of conventional design and construction. It had a nominal capacity of 25 cases; overall dimensions are given in Figure 2. The cooling unit was a one-half ton window air conditioner set to maintain a temperature of 55° to 60° F. in the cabinet.

The data on difference between egg surface minus air temperature were analyzed by linear analysis of regression of the logarithm of the dimensionless ratio:

$$\Delta t_o/\Delta t_i$$

on elapsed time, θ, to produce egg cooling rate equations of the form:

$$\theta = C_1 \log (\Delta t_o/\Delta t_i) + C_2 \quad \text{(eq. 1)}$$

where:

θ= elapsed time since cooling started, in hours.

Δt_o =temperature difference, degrees F., surface of warm egg minus cooler air temperature at beginning of cooling period.

Δt_i =temperature difference, degrees F., surface of egg minus cooler air temperature, after θ hours elapsed while cooling occurred.

C_1, C_2 =constants, with dimensions of time in hours

The constants, C_1 and C_2 for each egg and basket position are listed in Table 5.

These prediction equations have been applied to a typical egg cooling situation to illustrate how the time required to cool eggs varies with egg and basket position.

TABLE 5.—Constants for Egg Cooling Rate Equation:
$\theta = C_1 \log (\Delta t_o / \Delta t_i) + C_2$

Basket Position*	Egg Position In Basket	C_1 (hrs.)	C_2 (hrs.)
1	Center	8.37	+0.292
	Outer	6.03	—0 333
2	Center	7.05	+0.561
	Outer	3.69	+0.098
3	Center	5.23	+0.329
	Outer	2.98	+0.028

* Refer to Figure 2, page 11.

Results

Results are shown in Table 6 for typical conditions that include: Cooler temperature, 55° F.; initial egg temperatures of 100° F. and 90° F., respectively; and final egg temperatures of 60° F., 57° F., and 56° F., respectively.

Large differences occurred in cooling time. For example, to cool eggs from 100° F. to 60° F. required 8.3 hours for eggs in the center of a wire basket placed at the far end of the shelf (position 1); but only 5.3 hours for the same conditions except that the basket was 4 ft. closer to the cooling unit. Longer time was required to cool the eggs in the center of the basket than to cool eggs placed toward the outside. For example, in basket position 3, with initial egg temperature of 100° F., 5.3 hours were required to cool eggs at the basket center to 60° F., but only 2.9 hours for eggs placed to the outside of the basket.

TABLE 6.—Egg Cooling Times for Cooler Temperatures of 55° F., Eggs in Standard Wire Baskets

Basket Position*	Egg Position In Basket	Egg Temperature At Beginning Of Cooling Period (*degrees F.*)	Hours Required To Cool To Egg Surface Temperatures Of		
			60°F.	57°F.	56°F.
1	Center	100	8.3	11.6	14.1
		90	7.4	10.7	13.2
	Outside	100	5.4	7.8	9.6
		90	4.8	7.2	9.0
2	Center	100	7.3	10.1	12.2
		90	6.5	9.3	11.4
	Outside	100	3.6	5.1	6.2
		90	3.3	4.7	5.8
3	Center	100	5.3	7.4	9.0
		90	4.7	6.8	8.4
	Outside	100	2.9	4.1	5.0
		90	2.5	3.7	4.6

* Refer to Figure 2, page 11.

COOLER ENERGY USE

Knowledge of how electrical energy use by a farm egg cooler varies with cooler design and operating variables can be used in estimating egg cooling costs and in selecting a cooler design. An experiment was conducted to obtain data on energy use by typical farm egg coolers. The objective was to develop a prediction equation for electrical energy use by the refrigerative units of farm egg coolers as a function of cooler design and operational variables.

Preliminary Study

A supplementary study was conducted to measure the temperature of the eggs at the time they were placed in the cooler. An analysis of the collected data yielded an expression for egg internal temperature as a function of ambient outdoor temperature at the time the eggs were placed inside the cooler.

Eggs were gathered from nests at the University Poultry Farm laying houses at approximately two-hour intervals during the working day. Egg temperatures were sampled with a thermocouple probe. A total of 220 eggs were sampled at 16 intervals from April 12 through May 4 to obtain simultaneous observations of egg shell and ambient air temperatures. These data were analyzed to obtain a regression expression for egg shell temperature as a function of ambient air temperature when the eggs were placed in the cooler. The regression equation obtained was: $t_{sh} = 23.45 + 0.736\ t_a$ where t_{sh} is predicted shell surface temperature and t_a is air ambient temperature, all in degrees F.

Next a regression of egg interior temperature as a function of shell temperature was obtained by sampling simultaneously the shell surface and interior temperatures. Four eggs were sampled each day for 8 days, in the period May 10 through June 22, for a total of 32 eggs. The regression expression obtained was: $t_{in} = 46.11 + 0.539\ t_{sh}$ where t_{in} is egg interior temperature, and all temperatures are in degrees F.

Combination of the two foregoing equations yielded the expression:

$$t_{in} = 58.75 + 0.397\ t_a$$

This expression was used to estimate the interior temperatures of eggs at the time they were placed in the cooler.

Methods

The general procedure followed in conducting the experiments was to meter the electrical energy use by two typical egg coolers. Data were also collected for egg loading rate, and ambient temperatures inside and outside the cooler.

A 7 case nominal size egg cooler and a 25 case cooler were used in the experiments. The 7 case cooler had outside overall dimensions of 3 ft. 0 in. by 2 ft. 8¼ in. by 5 ft. 4 in. high (Figure 3). Construction was panelized. Panels consisted of ½-inch exterior type plywood for the outer faces and ⅛-inch tempered hardboard for the inner faces with a 2-inch (nominal) filling of batt-type insulation. Cooling effect was obtained with a ⅓ hp. residential window-type air conditioner installed in the cooler side wall near the top.

The 25 case cooler was the walk-in type and similar in construction to the 7 case cooler. Its overall dimensions were 6 ft. 8⅛ in. by 6 ft. 8⅛ in. by 6 ft. 6 in. high. Panels were faced with ⅛-inch tempered hardboard on the inside and ½-inch exterior type plywood on the outside. A 4-inch (nominal) filling of batt-type insulation was used for the walls and ceiling. The cooler was installed on an existing concrete floor. Cooling effect was provided by a ½ hp. residential window air conditioner installed in the rear wall near the top.

Figure 3. Shop-built, 7 case egg cooler used in experiments.

Overall (air-to-air) conductances or "U" values of the components of the coolers were measured by heat meter surveys under operating conditions. Mean "U" values, weighted on a component area basis, were found for the two coolers, as follows:

25 case cooler	0.0867 btu/hr.-deg.-sq. ft.
7 case cooler	0.0893 btu/hr.-deg.-sq. ft.

Electrical energy use by each of the two coolers was metered by an integrating watt-hour meter. Dry-bulb temperatures of the ambient air inside and outside the cooler were measured by recording thermographs.

During the experiment, the coolers were used for cooling and holding eggs gathered from the University Poultry Farm. Eggs were gathered at approximately 2-hour intervals during the working day. Eggs were cooled in wire baskets, then cased in standard cardboard egg cases kept in the coolers. The eggs were marketed once each week. All eggs gathered on the day of marketing were held in the cooler until the following week. Thus, the energy use for the coolers included cooling all of the eggs loaded into the cooler during one week.

Results

The quantities which were considered to have significant effect on cooler energy use are listed in Table 7. Cooler surface area, Item 4, was evaluated as 68.56 for the 7 case cooler, and 220.0 sq. ft. for the 25 case cooler. A constant value of 0.772 btu/(lb.) (deg. F.) was used for the specific heat of eggs.

By a well-known theorem of dimensional analysis of physical systems, it is known that the quantities which characterize the behavior of a physical system (in this case, the energy-using egg coolers) can be combined into a set of dimensionless parameters. The number of inde-

TABLE 7.—Quantities Influencing Energy Use by Farm Egg Coolers

No.	Symbol	Description of Quantity And Usual Dimensions	Dimensional Symbols	Remarks
1	Q	Btu equivalent of electrical energy metered to the cooling unit for refrigeration, btu per 24 hours	HT^{-1}	Measured by an integrating watt-hour meter.
2	Δt_e	Egg temperature when placed into cooler minus average ambient air temperature in cooler, degrees F.	θ	Egg temperatures when placed in cooler estimated by prediction equation (See page 14)
3	Δt_c	Average ambient air temperature outside cooler minus average ambient air temperature inside cooler, degrees F.	θ	Determined from thermograph continuous traces
4	λ	Outer surface area of cooler roof, walls, and floor, sq. ft.	L^2	Computed total surface area
5	U_m	Weighted mean "U" value for cooler construction btu/(ft.^{2}) (deg. F.) (hr.)	$HT^{-1}L^{-2}\theta^{-1}$	Determined from heat flow meter measurements
6	ρ	Weight of eggs placed in cooler per 24 hr. period, lb. per 24 hr.	MT^{-1}	Determined from entries on cooler loading log
7	C_e	Mean specific heat of eggs btu/(lb.) (deg. F.)	$HM^{-1}\theta^{-1}$	Published value used

pendent and dimensionless parameters which can be formed is equal to the number of quantities minus the rank of the dimensional matrix of quantities involved.

In the present study, seven quantities were included. The rank of the dimensional matrix was found to be 4. Thus, three independent and dimensionless parameters can be formed. The three that were used for analysis of the data were:

$$\Pi_1 = Q/(C_e \rho \Delta t_e)$$
$$\Pi_2 = \Delta t_c/\Delta t_e$$
$$\Pi_3 = U_m \lambda/(C_e \rho)$$

It was hypothesized on the basis of trial plotting that Π_1 could be expressed as a function of Π_2 and Π_3 as follows:

$$\Pi_1 = C_1(\Pi_2 \times \Pi_3)^n$$

where C_1 and n are a dimensionless coefficient and exponent, respectively.

The pi terms, Π_1, Π_2, and Π_3 were evaluated for a total of 59 observational periods in June, July, and August, for the 7 case and 25 case coolers, each. The data, plotted on log-log coordinates, are shown in Figure 4. Regression equations fitted to the data by statistical analysis are also shown in Figure 4. The regression for the pooled data appeared to adequately predict performance of both sizes of coolers. This equation obtained by regression analysis is:

$$\Pi_1 = 68(\Pi_2 \times \Pi_3)^{0.81}$$

or, using the appropriate quantities:

$$\frac{Q}{C_e \rho \Delta t_e} = 68 \times \left[\frac{U_m \lambda \Delta t_c}{C_e \rho \Delta t_e}\right]^{0.81}$$

If a value of 0.772 is used for the specific heat of eggs, and the energy use "Q", in btu, is converted to kilowatt hours, "E", by the factor 1/3414 kilowatt hours per btu, and the expression then rearranged as an explicit function of "E", the equation obtained is:

$$E = 0.0199\ (U_m \lambda \Delta t_c)^{0.81}\ (\rho \Delta t_e)^{0.19} \qquad \text{(eq. 2)}$$

"E" is kilowatt-hours of electrical energy used by the refrigerative unit per 24-hour period, and the other quantities are as defined in Table 7.

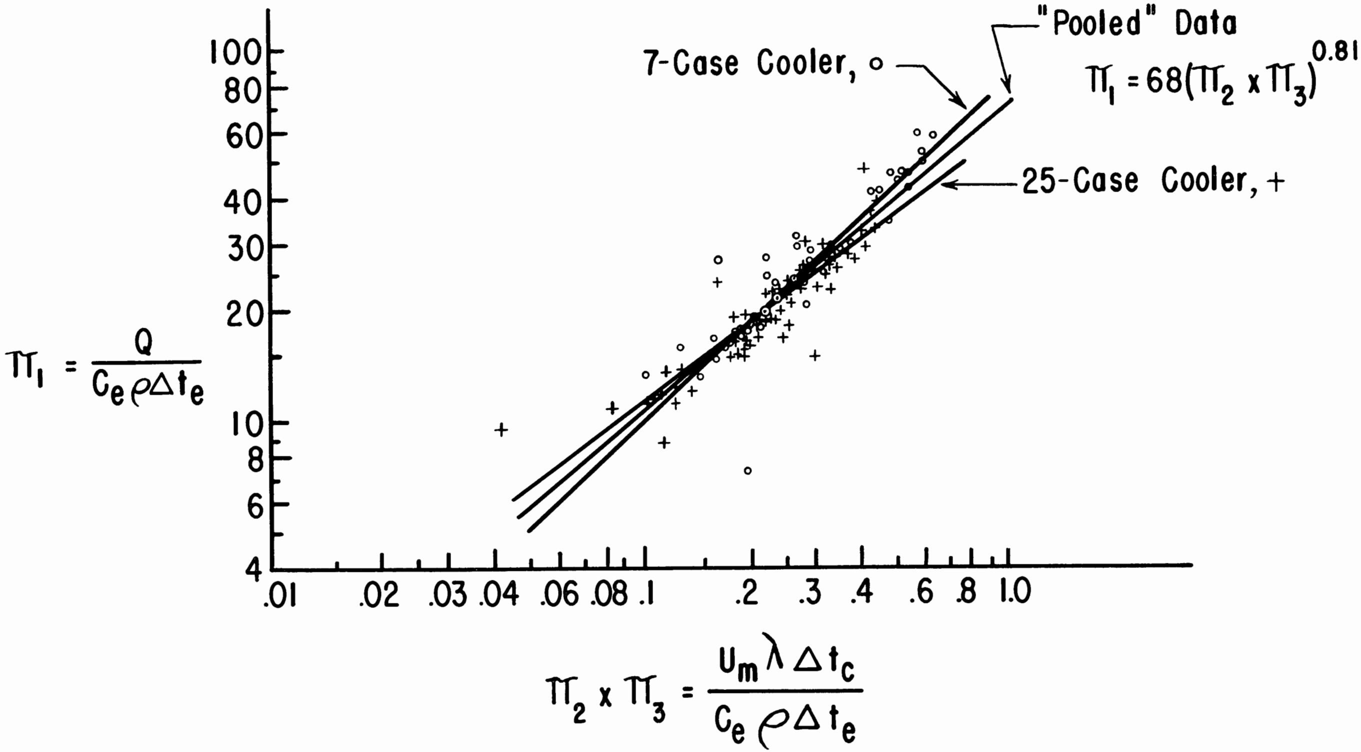

Figure 4. Prediction equation and experimental points for energy use by farm egg coolers.

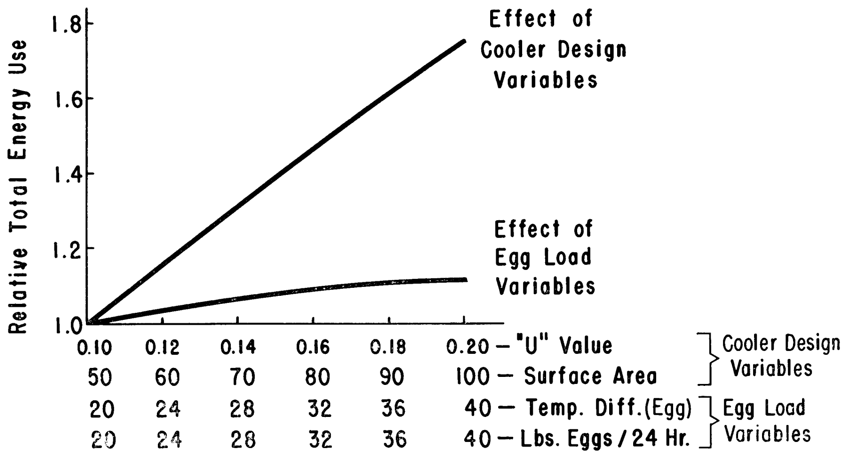

Figure 5. Effect of farm egg cooler design and loading variables on relative energy use for cooling and holding eggs.

It should be noted that the energy use "E" predicted by equation 2, above, is the total electrical energy metered to the refrigerative cooler, rather than the cooling load. Equation 2 should be valid for any farm egg cooler with a comparable type of refrigerative unit and used under conditions comparable to those in the present experiments. Equation 2 can be used to estimate the effects of design and management variables on electrical energy use by the refrigerative unit.

Inspection of the equation reveals that, in regard to electrical energy use, the design of the cabinet and the temperature of the room or space where the cooler is located are of much more importance than the amount and initial temperature of the eggs placed in the cooler. This is illustrated in Figure 5. For example, if the energy used by a cooler with a mean "U" value of 0.10, and a surface area of 50 sq. ft. is assigned a relative value of 1.0, the energy use will be increased approximately 75 percent if either the "U" value or surface area is doubled. In contrast, the energy use will be increased only 14 percent if the egg loading rate is doubled.

For economical egg cooling, the egg cooling cabinet should be well insulated ("U" value of 0.10 or smaller), kept in a relatively cool space, and be no larger than necessary to accommodate, when fully loaded, all the eggs accummulated by the end of the holding period.

MILK CAN COOLERS FOR EGG COOLING AND HANDLING

Conversion from can to bulk cooling of milk on dairy farms has made surplus milk can coolers available at bargain prices in some areas. These surplus can coolers were thought to be useable as low cost egg coolers.

Methods

Two second-hand can coolers were used in this experiment.* Electrical energy by each of the coolers was metered with a watt-hour meter. The data on electrical energy use were converted to an equivalent of kilowatts per cubic foot of cooler volume, per degree F. temperature difference between the cooler interior space and the ambient air outside the cooler, or, kilowatts/(cu. ft.-deg. F.).

Results

This energy use rate for the large can cooler of the ice-bank type was 1.1×10^{-4} kilowatts/(cu. ft.-deg.). For the small can cooler, the rate was 7.43×10^{-4} kilowatts/(cu. ft.-deg.) and 5.02×10^{-4} kilowatts/(cu. ft.-deg.). The higher rate occurred with the immersion coil submerged in a drum of water with free convection heat transfer from the drum surface to the air in the cooler box. Subsequently, a small fan was installed in the cooler box to circulate air around the drum surface. This produced forced convection and increased the heat transfer coefficient. As a result, the cooling energy use rate was lowered.

It was apparent that milk can coolers can vary by several fold in efficiency in using electrical energy for cooling eggs. Evaporator coil area and arrangement, as well as mechanical condition of the compressor, accounted for the difference. Ice-bank type can coolers have more coil area and better exposure to the air in the cabinet than immersion type coolers with a smaller, more concentrated coil. As a result, ice-bank can coolers were expected to operate more efficiently. This was verified by the results, which revealed that the immersion cooler had an energy use rate at least 4½ times that of the ice-bank cooler.

It was concluded that can coolers of the ice-bank type with the evaporator coils encircling the interior space may be suitable for egg coolers if the refrigeration unit is in good operating condition, and if the operator is willing to accept some inconvenience in loading and unloading the cooler.

*These coolers were in use in the experiments conducted on humidity control for egg cooling and holding, in the section "Egg Weight Loss." Description of the coolers is given on pages 7 and 14.

SUMMARY AND CONCLUSIONS

An experimental investigation was conducted to evaluate the effects of using on-the-farm egg cooling and holding facilities on egg commercial market grade. The effects of egg cooler design and operating variables on egg weight loss and electrical energy use by the refrigeration equipment, were experimentally established. Prediction equations were developed for cooling rate as a function of cooler temperature and position in the cooler. Prediction equations were established for cooler energy use as a function of egg cooler design and operational variables. Limited trials were conducted on the suitability of used milk can coolers for cooling eggs.

Conclusions drawn from the study included the following:

1. The use of refrigerated facilities to cool newly laid eggs and hold them at temperatures of 58° to 61°F. resulted in approximately 20 more Grade A eggs per 100 marketed, (84.5 percent compared to 63.0 percent), compared to eggs marketed from non-refrigerated storage during the months May through August. Eggs were marketed at weekly intervals.

2. Yearly average number of Grade A eggs marketed at one-week intervals from the refrigerated storage was approximately 10 more eggs per 100 compared to eggs marketed from non-refrigerated storage (91.1 percent compared to 81.0 percent).

3. The yearly average return above cooler overhead and operating costs from the use of refrigerated egg cooling and holding facilities was 78/100 of a cent per dozen, for all eggs marketed at one-week intervals.

4. The break-even point (returns from refrigeration equal to cooler fixed plus operating costs) was an average cooler loading rate of approximately one-half case per day for a typical 7 case cooler; and approximately 1 case per day for a typical 25 case cooler. Above these break-even points, returns from cooling increased almost linearly with loading rate.

5. Egg weight loss during refrigerated storage (52° to 56°F.) was significantly affected by relative humidity level, and by storage in a wire basket compared to a standard cardboard carton. Use of a commercial sprayed-on sealant on the eggs had a noticeable but probably less important effect than the humidity level and type of storage container used.

6. Minimum weight loss of 0.13 percent of the original weight per week occurred for storage in a high relative humidity atmosphere (89 percent average) with eggs initially sprayed with a commercial sealant and contained in a standard cardboard case.

7. Maximum weight loss of 0.99 percent of the original weight per week occurred for storage in a low relative humidity (47 percent average) for eggs contained in a wire egg basket, and not sprayed with a sealant.

8. Weight loss rate for eggs in a cardboard container at a medium humidity (68 percent) was 0.27 percent per week when a sealant was used, and 0.39 percent when no sealant was used. This humidity level prevailed without special humidification equipment or humidity control.

9. Time required to cool eggs contained in a wire basket from temperature at gathering to 57° F. (cooler air temperature of 55° F. plus 2 degrees) differed by several hours due to position of the basket with respect to the path of air circulation from the refrigerative cooler unit, and the position of the egg within the basket.

10. Cooling time for eggs, initially at 90° F. and cooled to 57° F. (cooler temperature plus 2 degrees), was 10.7 hours for eggs at the center of a standard wire egg basket placed 5 ft. from the wall in which the cooler unit was mounted. Cooling time was only 6.8 hours (approximately 4 hours less) when the basket was positioned 1 ft. from the wall.

11. The electrical energy use by refrigerated farm-type egg coolers was found to be predictable by an equation of the form: $Q/(C_e \times \rho \times \Delta t_e) = C_1 \times [(U_m \times \lambda \times \Delta t_e)/(C_e \times \rho \times \Delta t_e)]^n$, where the quantities are defined in Table 7, and generally refer to cooler design and operating variables. Values for C_1 and n were found to be 68 and 0.81, respectively, in the present study.

12. In regard to efficiency in using electrical energy for cooling eggs, the design of the cabinet (size and amount of thermal insulation) and the temperature of the room where the cooler is installed were much more important than the number of eggs cooled. Under typical conditions, doubling the thermal "U" value or doubling the cooler box surface area increased electrical energy use by 75 percent. In contrast, doubling the egg loading rate only increased energy used by 14 percent.

13. Surplus or used milk can coolers of the ice-bank type (evaporator or cold coils encircling the interior walls) were found to be usable for cooling eggs. Energy use rate for a typical reconditioned can cooler when used for cooling eggs during hot weather was 1.1×10^{-4} kilowatts per (cu. ft. of cooler volume $\times$ degree F. temperature difference between ambient and cooler temperature).

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