TEMPERATURE VARIATIONS IN FARM MILK TRANSPORTED UNDER SUBTROPICAL CONDITIONS

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SUMMARY

The mean temperature increase in milk during transport in cans in motor vehicles for 25-40 miles from farm to factory, with air temperatures of 73.2-86.0°F, was 6-10°F. A total of 7.3 per cent. of samples exhibited an increase of 20° or more, 29.2 per cent. an increase of 10-19°, 54.3 per cent. an increase of 0-9°, and 9.2 per cent. a temperature decrease during transit.

For milk in cans completely protected from air currents, rate-of-heating constants were 0.0096 and 0.0118, in comparison with 0.0223 for milk in cans transported in a vehicle with an open-slat superstructure. Temperature increases of milk in sealed vehicles were approximately 2-4°F lower than those of milk in open-slat vehicles.

Can position in the vehicle affected the temperature change. Milk temperature of "inside" cans increased at a lower rate than that of milk in "outside" cans.

I. INTRODUCTION

In countries where dairying is conducted under warm climatic conditions the keeping quality of milk is severely lowered unless the milk is cooled to a low temperature immediately after it is produced and then stored at low temperature.

Considerable information is available on the effects of health of cow, cleanliness of equipment, preparation of the cow, milking techniques, and temperature of cooling and storage on milk quality (Kelly and Clement 1931; Roadhouse and Henderson 1941; Harvey and Hill 1946; Cronshaw 1947). However, little work has been reported on the influence of transport conditions in hot climates on the temperature of milk. While producers have been advised of the advantages of cooling to and storage at low temperature on the farm, the importance of preventing a rise in temperature after the dairy produce has left the farm has not received the same attention.

Abraham and Outwater (1944) found under conditions of transport in New York State an average temperature increase in night's milk to New York from 47·8° to 52·2°F in uncooled vehicles and an average increase from 52·7° to 52·8°F in iced vehicles.

Pesk (1944), after examining the influence of temperature in open and closed truck hauling in the U.S.A., reported marked differences in internal

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temperatures between the two constructions. Floor temperatures of 70°F in the closed vehicle and 88°F in a partially open vehicle operating under similar atmospheric conditions were obtained. Temperatures in the partially open vehicle were found to vary with wind direction.

Working in England, Brindley, Scarlett, and Rowlands (1946) reported a change of 20°F in the temperature of milk in cans standing in the sun for six hours and a change of 10°F for cans stored in the shade during summer months. Jenkins, Reeve, and Provan (1949) investigated the effect of transport in open and enclosed vehicles, also in England. They stated that no useful purpose is served by protecting the cans from the direct heat of the sun during transit, irrespective of the temperature of the milk when cooled.

Brandsma and Hunt (1959) determined the temperature rise of refrigerated milk transported in closed, insulated trucks under atmospheric conditions ranging from 80° to 93°F. They concluded that the temperature of neighbouring cans, atmospheric temperature and length of time in transit are influencing factors.

In Queensland, Smythe (1945), investigating the influence of the "can factor" on milk quality using milk samples in tubes as controls, reported that time and duration of transport affected the fall in reduction of methylene blue times in a significant manner. Schubert (1956), correlating the quality of milk received in Brisbane milk factories with distance of transport and month of the year, reported that air temperature was an important factor in milk quality, and stressed the need for temperature control during storage on the farm and in transit.

In view of the increasing adoption of farm refrigeration for market milk supplies in Queensland, the investigation reported here was undertaken to determine the variations in milk temperature during transit under summer conditions from farm to factory in vehicles of variable construction.

No attempt was made to determine the keeping quality of experimental samples by the recognized milk quality tests because of the unknown history of the milk before pick-up and the difficulties associated with eliminating the influence of the "can factor" on quality.

II. METHODS

(a) Sampling Conditions

Temperature recordings were made on the same day at approximately fortnightly intervals during the period October 1957 to March 1958. The summer period was selected for sampling as the high atmospheric temperatures provided the most severe conditions for evaluating transport in covered vehicles.

The first can was loaded on to vehicles between 6.45 a.m. and 7.15 a.m. and vehicles arrived for unloading at processing depots between 10.00 a.m. and 10.45 a.m. Due to congestion at the factory it was usual for vehicles to stand for 1–1½ hr in the sun prior to unloading. In the case of Vehicles A and B, temperature recordings on closed vehicles were made on immediately succeeding days to the open-vehicle trial.

Recordings were made on a total of 1,671 cans.

(b) Vehicle Construction

McDowall (1953) and McWhirter (1956) have reported that accepted practice throughout New Zealand and Australia is for authorities controlling the production and supply of dairy produce to require vehicles transporting produce in cans to be covered to provide protection from direct sunlight on can surfaces.

The relevant regulation of *"The Dairy Produce Acts,* 1920 *to* 1959," of Queensland is as follows:

"Reg. 128. The owner of a conveyance used for the carriage of cream or milk to any other conveyance, butter factory, cream or milk depot, railway station, or railway siding, or other dairy produce premises, shall provide such firstmentioned conveyance with a permanent cover of wood, approved canvas, or other approved material which shall effectively protect from the sun's rays the dairy produce carried upon such firstmentioned conveyance. Such cover shall be not more than 5 feet 6 inches from the floor of the conveyance, with not less than 12 inches overhang on the sides and at the back. Where the cans are carried in two tiers there shall be a space of at least 3 inches clear above the bottom can and at least 9 inches clear between the top can and the roof. The sides shall be constructed of an approved louvre or boarded with timber not less than one-half inch thick, with a space of at least one-half inch between each board to a height of 3 feet 6 inches from the floor of the conveyance. The back shall be constructed in a like manner, and be in the form of a moveable tailboard: Provided that where milk or cream is conveyed by the person producing such milk or cream, this regulation shall not apply if a cover of canvas or other approved material is used to effectively protect such milk or cream against the sun's rays; such cover shall be affixed in such a manner as to afford ventilation between the can and such cover."

As such legislation only prescribes minimum requirements, a variety of interpretations of vehicle construction is possible. An earlier independent survey indicated that this variation in construction occurred in Queensland.

The regulations under Acts of various Australian States governing dairy produce do not prescribe conditions for the control of the movement of air around the cans during transit. Under weather conditions prevailing in Queensland during summer, where mid-morning temperatures approximate 85–95°F on many days, such air movement around cans containing refrigerated milk causes marked increases in temperature. Vehicle construction in this investigation was modified therefore to determine the influence of various forms of covering on the extent of milk temperature increase during transit.

Five vehicles providing seven different types of conditions were used initially, but owing to difficulties in obtaining similar pick-up temperatures with one pairing (Vehicles D and E), this section of the trial was discontinued after five comparisons. The modified pick-up system was restricted to three vehicles providing five different conditions of transit.

TABLE 1

Details of Transport Conditions

Vehicle	Maximum Load (cans)	Classification	Transport Distance (miles)	Transport Time	Construction
				hr min	
A	Lower = 90 Upper = 36	Open ..	37	3 30	Conventional slat construction Hood 6 ft from tray. Open rear
A1	,,	Closed ..	,,	,,	Vehicle A completely enclosed with canvas hood
B	Lower = 90 Upper = 72	Closed (partially)	40	2 50	Complete seal of sides. Front end sealed to lid of can in upper tier. Hood 5 ft 9 in. from tray. Open rear
B1	,,	Closed ..	,,	,,	Vehicle B completely enclosed with light timber and rear flap
C	Lower = 90 Upper = 66	Closed (partially)	38	4 00	Complete seal of sides and ends to shoulder of can in upper tier. Hood 5 ft 9 in. from tray
D	Lower = 78 Upper = 42	Open ..	31	3 00	Conventional slat construction similar to A. Hood 5 ft 9 in. from tray. Open rear
E	Lower = 78 Upper = 30	Closed ..	26	3 00	Completely enclosed construction with timber similar to B1. Hood 5 ft 9 in. from tray. Open rear

Details of vehicle construction, together with loadings, distances and transit times, are summarized in Table 1. Vehicles are illustrated in Figures 1–7.

On arrival at the factory, a visual examination for excessive dust contamination was made of cans in closed vehicles.

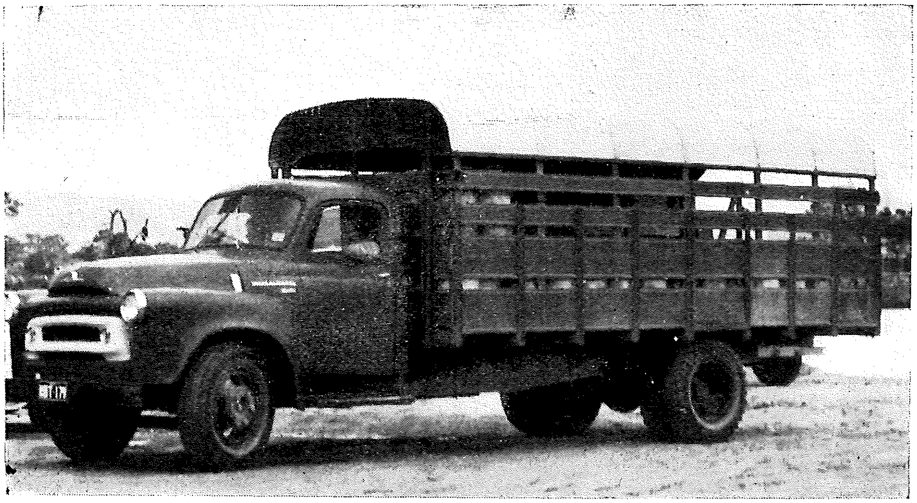

Fig. 1.—Vehicle A. Conventional slat cover typical of milk transport vehicles. Note that this structure permits air movement around cans.

Fig. 2.—Vehicle A enclosed with a heavy-duty canvas canopy (Vehicle A1). Both front and rear ends are protected with separate flaps.

Fig. 3.—Vehicle B. Timber sides of vehicle sealed to provide complete protection from draught. Open slat in front end permits air movement above surface of cans.

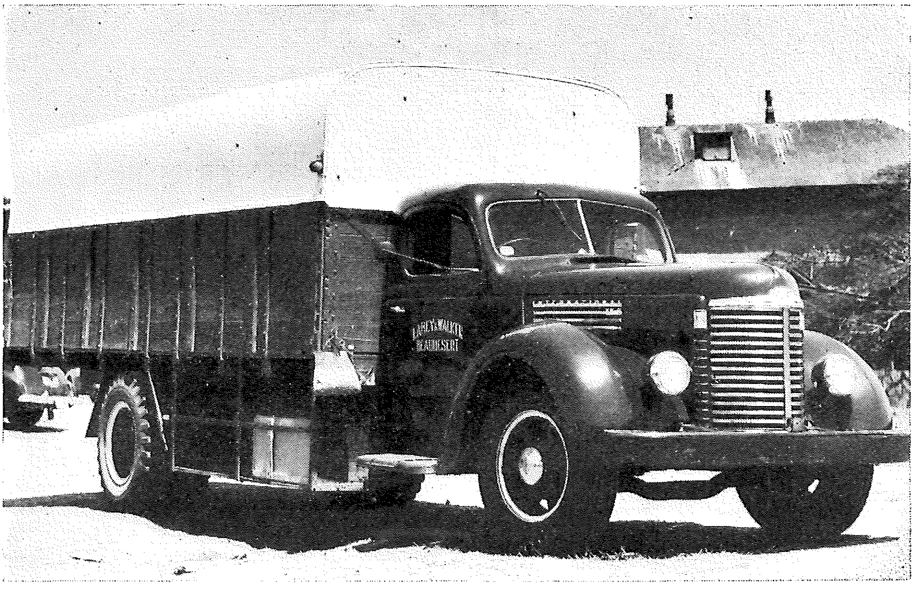

Fig. 4.—Vehicle B completely sealed with a timber insert at front end and a canvas flap on rear end (Vehicle B1)

Fig. 5.—Vehicle C. Timber inserts fitted to conventional structure to restrict air movement to upper tier of cans.

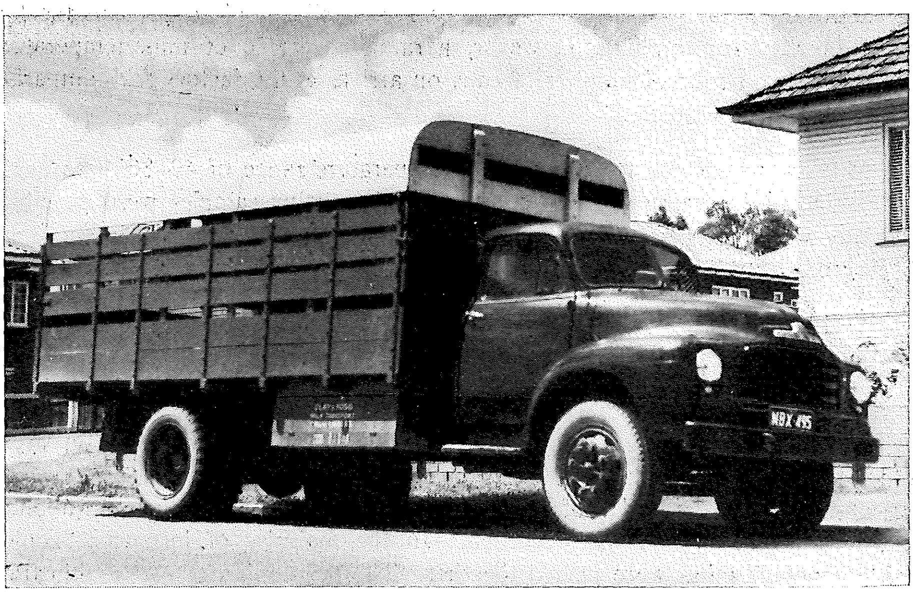

Fig. 6.—Vehicle D. Small-capacity vehicle of conventional structure. Compare with Vehicle A (Fig. 1).

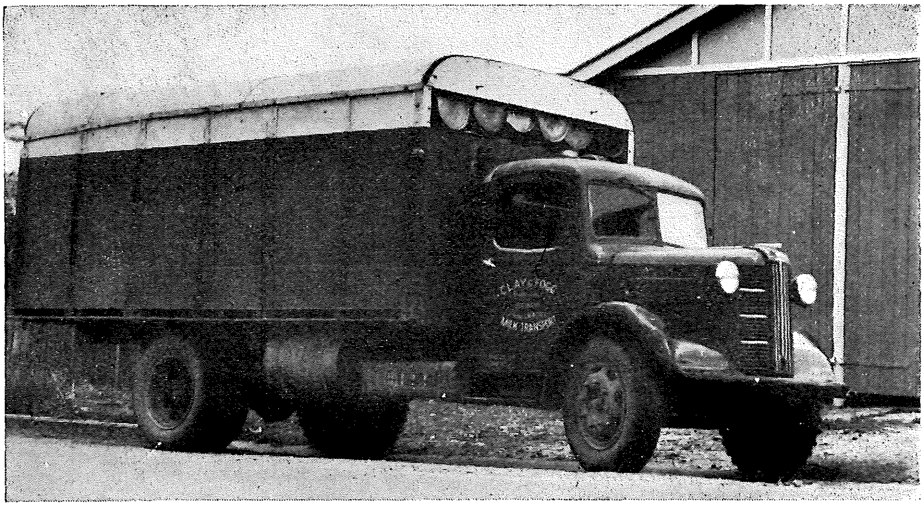

Fig. 7.—Vehicle E. Small-capacity vehicle with completely sealed sides. During transit the front end was sealed with a timber insert but rear end remained open.

(c) Milk Temperature

The temperature of the milk was recorded at the point of pick-up at the farm gate and at the time of tipping at the processing factory. The temperature rise in milk which occurred as a consequence of vehicles standing in the sun awaiting tipping was included therefore in the overall temperature rise. This was unavoidable, as it was not possible to record all sample cans until the load was discharged for tipping. However, a random sample of milk temperatures was recorded on a small number of cans on arrival at the factory for comparison with tipping temperatures.

Milks were selected to embrace the temperature range of 40–80°F to ensure that refrigerated evening supplies and uncooled morning samples were examined. Difficulty was experienced in securing a large number of samples in the above 80°F group.

Temperatures were recorded to the nearest °F.

(d) Can Position

Sample cans were selected according to a predetermined position in the vehicles. Cans 1, 3, 4 and 6 of Rows 1, 5 10 and 15 were recorded in the lower tier, and Cans 1, 3, 4 and 6 of Rows 1, 5 and 10 in the upper tier. In addition, Can 1 in adjacent rows was recorded. In the majority of instances "cooled" and "uncooled" milks were placed together. The positioning of cans is illustrated in Figure 8. Similar positioning of sample cans was arranged for trucks of covered construction in comparative trials.

Positioning of sample cans enabled groupings of "inside" and "outside" cans to be arranged when analysing results for temperature differences.

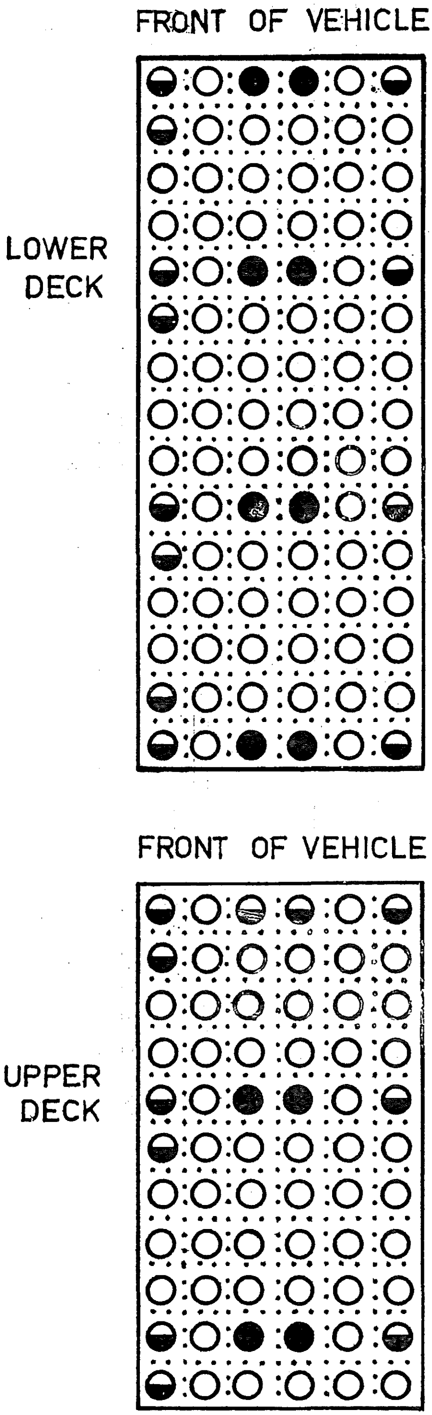

Fig. 8.—Diagram showing position of sample cans. The filled circles were regarded as "inside" positions.

TABLE 2
Mean Milk Temperatures, Vehicles A and A1

Temperature Range (°F)	Vehicle A (Open)					Vehicle A1 (Closed)					Significance of Difference between Means
	Cans		Mean Temperature of Milk (°F)			Cans		Mean Temperature of Milk (°F)			
	No.	%	At Farm Gate	On Factory Platform	Increase	No.	%	At Farm Gate	On Factory Platform	Increase	
50 and below ..	58	23·5	46·9	63·8	16·9 ± 0·68	57	23·1	46·2	58·8	12·6 ± 0·60	Sig. (1%)
51–60	90	36·4	55·3	67·4	12·1 ±0·47	85	34·4	55·9	63·2	7·3 ± 0·36	Sig. (1%)
61–70	87	35·2	64·9	70·4	5·5 ± 0·31	97	39·3	64·4	68·0	3·6 ± 0·61	Sig. (1%)
71–80	10	4·1	72·6	74·6	2·0 ± 0·54	8	3·2	72·3	73·8	1·5 ± 0·52	Not sig.
81 and over ..	2	0·8	81·5	82·5	1·0	..	0	..	..	..	..
Total ..	247		57·6	68·0	10·4 ± 0·40	247		57·5	64·4	6·9 ± 0·30	Sig. (1%)

TABLE 3
Mean Milk Temperatures, Vehicles B and B1

Temperature Range (°F)	Vehicle B (Partially Closed)					Vehicle B1 (Closed)					Significance of Difference between Means
	Cans		Mean Temperature of Milk (°F)			Cans		Mean Temperature of Milk (°F)			
	No.	%	At Farm Gate	On Factory Platform	Increase	No.	%	At Farm Gate	On Factory Platform	Increase	
50 and below ..	133	39·7	44·7	61·4	16·7 ± 0·55	129	38·5	44·5	57·7	13·2 ± 0·37	Sig. (1%)
51–60	61	18·2	56·1	64·2	8·1 ± 0·44	69	20·6	55·6	62·6	7·0 ± 0·38	Not sig.
61–70	86	25·7	65·8	69·2	3·4 ± 0·29	77	23·0	65·5	67·5	2·0 ± 0·22	Sig. (1%)
71–80	50	14·9	75·8	74·9	−0·9 ± 0·28	51	15·2	75·7	74·4	−1·3 ± 0·21	Not sig.
81 and over ..	5	1·5	81·8	81·0	−0·8± 0·90	9	2·7	81·4	78·0	−3·4 ± 0·53	Sig. (5%)
Total ..	335		57·4	66·2	8·8 ± 0·45	335		57·4	64·1	6·7 ± 0·36	Sig. (1%)

(e) Weather Conditions

As movement of air through the vehicles was the main factor causing milk temperature increases, air temperatures were recorded at hourly intervals while the vehicles were in motion. These records were checked against official meteorological recordings in the producing area. The air temperature at 9.00 a.m. was regarded as typical of weather conditions during transit unless wide hourly fluctuations occurred. This time approximated the middle of the collection journey.

III. RESULTS

(a) Increase in Milk Temperature

Results of mean temperature recordings on milk when loaded into the transport vehicle at the farm gate, and on unloading on the factory receival platform, are listed for the several vehicles in Tables 2–6. Initial temperatures were grouped in 10°F ranges from "50°F and below" to "81°F and above." Differences in milk temperature increases between farm and factory for open and closed vehicles were examined for significance.

TABLE 4

Mean Milk Temperatures, Vehicle C

Temperature Range (°F)	Vehicle C (Partially Closed)				
	Cans		Mean Temperature of Milk (°F)		
	No.	%	At Farm Gate	On Factory Platform	Increase
50 and below ..	58	19·2	45·4	64·8	19·4 ± 0·69
51–60	90	29·7	55·9	64·5	8·6 ± 0·53
61–70	101	33·3	63·8	67·7	3·9 ± 0·30
71–80	41	13·5	74·0	74·0	0 ± 0·36
81 and over ..	13	4·3	82·5	80·3	−2·2 ± 0·49
Totals ..	303		60·1	67·6	7·5 ± 0·45

(i) Vehicle A

This trial provided a comparison between the conventional open-slat construction (see Reg. 128) and the completely closed structure. Closure was obtained by fitting a canvas hood over the existing superstructure and fitting a rear canvas flap.

TABLE 5

Mean Milk Temperatures, Vehicle D

Temperature Range (°F)	Vehicle D (Open)				
	Cans		Mean Temperature of Milk (°F)		
	No.	%	At Farm Gate	On Factory Platform	Increase
50 and below ..	39	38·2	45·5	62·5	17·0 ± 0·81
51–60	31	30·4	54·7	62·3	7·6 ± 0·45
61–70	8	7·8	63·8	66·8	3·0 ± 1·01
71–80	11	10·8	77·7	76·0	−1·7 ± 0·59
81 and over ..	13	12·8	83·1	78·6	−4·5 ± 0·92
Total ..	102		58·0	66·3	8·3 ± 0·87

TABLE 6

Mean Milk Temperatures, Vehicle E

Temperature Range (°F)	Vehicle E (Closed)				
	Cans		Mean Temperature of Milk (°F)		
	No.	%	At Farm Gate	On Factory Platform	Increase
50 and below ..	41	40·2	44·9	56·9	12·0 ± 0·73
51–60	35	34·3	56·3	62·9	6·6 ± 0·70
61–70	11	10·8	63·7	66·2	2·5 ± 0·56
71–80	15	14·7	74·3	73·9	−0·4 ± 0·64
81 and over ..	..	..	..	..	..
Total ..	102		55·2	62·5	7·3 ± 0·59

Mean milk temperature increased from 57·6° to 68·0°, an increase of 10·4°, in the open vehicle, and from 57·5° to 64·4°, an increase of 6·9°, with the enclosed superstructure (Table 2). This difference in "all cans" mean increase was significant statistically, as were the group differences in the temperature ranges "50 and below," "51–60" and "61–70."

The percentage distribution of individual can increases, grouped in 5° ranges, is listed in Table 7. These results indicate a wider range of distribution in milk from the open vehicle than with the closed construction. With the closed vehicle 25·5 per cent. of milks exhibited an increase in the "10° and over" range, compared with 49·0 per cent. of milks in the conventional open-slat construction.

(ii) Vehicle B

This trial provided a comparison between a partially enclosed and a completely enclosed vehicle. Complete closure was obtained by inserting a timber facing on the open front end and fitting a rear canvas flap.

Mean milk temperature increased from 57·4° to 66·2°, an increase of 8·8°, in the partially enclosed vehicle, and from 57·4° to 64·1°, an increase of 6·7°, in the completely closed type (Table 3). The difference in the "all cans" mean temperature increase between trucks was significant, as were the group differences in the temperature ranges "50 and below," "61–70" and "81 and over."

A comparison of the mean temperature increase of all milk in Vehicle A (closed) and Vehicle B (closed) reveals a close relationship of 6·9° and 6·7° respectively, which increases were not significantly different. There was a significant difference in the mean temperature increases obtained in the partially closed Vehicle B (8·8°) and the conventional open Vehicle A (10·4°).

In agreement with the "all can" difference in mean temperature increase between partially closed and closed vehicles, the percentage of individual can increases in the low temperature grouping was higher with closed construction than in the partially closed type (Table 7). This difference in distribution was not as marked as that which occurred between open and closed superstructure with Vehicle A.

A feature of this trial was the appreciable percentage of cans which exhibited a temperature decrease during transit, viz. 11·0 in the partially closed vehicle and 14·9 with the completely sealed construction. Table 3 shows that 15–20 per cent. of sample cans had initial milk temperatures approximating or exceeding atmospheric conditions (see Table 11), which circumstances could account for this slight cooling during transit. The influence of cooler neighbouring cans on individual temperature decreases is advanced as a further factor, especially in those instances where initial milk temperatures were below air temperature.

(iii) Vehicle C

In this trial mean milk temperature increased from 60·1° at the farm gate to 67·6° on tipping at the factory, a mean increase of 7·5° during transit (Table 4). This vehicle was partially enclosed, protection afforded being intermediate between Vehicle A (open) and Vehicle B (partially closed).

TABLE 7

Percentage Distribution of Increases in Milk Temperature of all Vehicles During Transit

Range of Temperature Increase (°F)	Vehicle A		Vehicle B		Vehicle C	Vehicle D	Vehicle E	Can Position		All Vehicles
	Open	Closed	Partially Closed	Closed	Partially Closed	Open	Closed	Inside	Outside	
Decrease ..	0·4	0·4	11·0	14·9	10·6	23·5	8·8	11·3	8·0	9·2
0– 4 ..	19·0	38·9	23·6	28·1	36·6	9·8	28·5	38·6	22·2	27·9
5– 9 ..	31·6	35·2	23·9	21·8	22·1	25·5	29·4	26·6	26·2	26·4
10–14 ..	21·1	17·8	17·9	22·1	9·6	16·7	20·6	12·9	20·5	17·8
15–19 ...	19·8	6·1	11·3	9·5	11·9	10·8	8·8	8·4	13·0	11·4
20–24 ..	4·9	1·2	7·2	3·6	5·9	12·7	3·9	1·9	6·9	5·1
25 and over ..	3·2	0·4	5·1	..	3·3	1·0	..	0·3	3·2	2·2

A smaller percentage of cans in the "50 and below" group resulted in the "all cans" mean farm milk temperature being higher than with Vehicle B.

A slightly increased percentage of cans exhibited low temperature increases with this trial in comparison with Trial B, due to the lower proportion of cans in the "50 and below" and "51–60" farm temperature ranges. As with Trial B, several cans exhibited initial milk temperatures in excess of 70° and subsequent cooling occurred during transit; 10·6 per cent. of all cans decreased in temperature between the farm gate and the factory.

(iv) Vehicle D

Mean milk temperature increased from 58·0° to 66·3°, an increase of 8·3° between farm pick-up and factory tip (Table 5).

The percentage of cans in the lower ranges of increases in temperature during transit ranged from 33·3 for "4 and below" to 13·7 for "20 and above." A comparison of this percentage distribution with the other open vehicle in the investigation, Vehicle A (open), indicated a wide difference in the lower ranges, Vehicle D exhibiting an increased percentage. This could be accounted for by the larger number of cans in the higher initial temperature grouping. Of all vehicles, this vehicle transported the greatest portion of milk "greater than 70°" and it exhibited the greatest percentage of milk which showed temperature decrease in transit.

(v) Vehicle E

In this trial mean milk temperatures increased from 55·2° at the farm to 62·5° at the factory, an increase of 7·3° (Table 6). Complete closure was obtained by inserting a timber facing on the open front end, the canopy sides already being sealed. No rear protection was fitted on this vehicle.

Because initial milk temperature was lower in this vehicle in comparison with milk on Vehicle D, higher increases would be expected during transit if the vehicle had been uncovered. However, it was found that the percentage distribution of individual cans increases in the lower ranges for milk in Vehicle E was much greater than with milk in Vehicle D. Of the cans in Vehicle E, 87·3 per cent. recorded increases of "14° and below" compared with 75·4 per cent. of cans in this range for Vehicle D, suggesting a beneficial effect from closing.

(b) Rate of Temperature Increase

As the rate of heating of a body under given conditions is proportional to the temperature difference between the body and its surroundings, individual can temperatures were related to atmospheric temperatures, distance of transport and types of covering. All milk temperatures for each vehicle at the farm and the factory were analysed according to the following formula:—

$$k = \frac{1}{m} \log_e \frac{\theta_A - \theta_O}{\theta_A - \theta_1}$$

where k = heating constant/mile /°F temperature difference between milk and atmosphere

m = miles in transit

θ_A = mean air temperature

θ_O = temperature of milk at farm

θ_1 = temperature of milk at factory

In this grouping no allowance was made for the influence of can position on temperature, as this effect should be similar for comparative recordings. It was not possible in the analysis to exclude the influence of neighbouring cans on individual temperature changes. It was noted that 161 cans of a total of 1671 examined recorded either a temperature decrease during transit, initial temperatures in excess of air temperatures or final temperatures in excess of air temperatures. These 161 cans were excluded in calculating the "k" value for vehicles.

Heating factors within the range ·0096 to ·0223 were obtained from the seven different constructions examined. Results are listed in Table 8. A marked difference in the rate of heating was evident between the vehicles of the conventional slat superstructure and the vehicles completely enclosed. In the former instance, with Vehicle A, a value of ·0223 was obtained, in contrast to factors of ·0096 and ·0118 when milk was transported in closed Vehicles B and A respectively.

The results obtained with Vehicle C (partially closed) could be considered relatively high although the protection afforded to cans was not as complete as with Vehicle B (partially closed).

(c) Position of Can

While initial farm and atmospheric temperatures are important in determining the final milk temperature after transport, the position of a can on the transport vehicle must be considered.

To examine the effect of "inside" and "outside" can positions on changes in milk temperature, results were segregated into "inner" and "outer" groupings and analysed. Rate-of-heating constants were also determined for cans in these positions to ascertain any variations in heating rate because of differing conditions of air movement around the external surface of the can. Differences in the rate of heating milk in "outside" and "inside" cans were found, the variation being widest in open vehicles. The results for the individual trucks are tabulated in Tables 8 and 9.

TABLE 8

Rate-of-Heating Constant for Cans in Various Positions

Vehicle	Construction	Total Cans Re-corded	" k " Factor					
			Inside Cans		Outside Cans		All Cans Analysed	
			No.	Factor	No.	Factor	No.	Factor
B1	Closed	335	98	·0078	188	·0104	286	·0096 ± ·0003
A1	Closed	247	82	·0096	164	·0128	246	·0118 ± ·0002
B	Partially Closed . .	335	111	·0104	189	·0155	300	·0136 ± ·0005
E	Closed	102	29	·0112	64	·0155	93	·0142 ± ·0010
D	Open	102	23	·0109	55	·0168	78	·0150 ± ·0009
C	Partially Closed . .	303	96	·0144	166	·0232	262	·0203 ± ·0008
A	Open	247	82	·0151	163	·0258	245	·0223 ± ·0008
		1,671	521		989		1,510	

The benefit of the additional protection afforded with closed superstructure to both inside and outside cans in trials on Vehicles A1 and B1 was reflected in the lower actual temperature increases and the lower final temperatures recorded for cans examined in these vehicles in comparison with results from Vehicles A and B.

(d) Temperature Increase on Standing

To determine the temperature increases in milk while vehicles were awaiting receival, the temperatures of a small number of cans were taken immediately on arrival and compared with temperature of milk at tipping. Results are listed in Table 10. The limited number of samples did not permit any differentiation between open and closed superstructure but only indicated a mean rise of the order of 1–2° for the 1–1½ hr standing period. This low rise supports the premise that where standing time is not excessive the major cause of temperature variation during transit is the movement of air through the vehicle.

(e) Atmospheric Temperature

Mean air temperatures at 9.00 a.m. on collection days are listed in Table 11. Air temperatures for the 6 months' sampling period averaged 80·7°, with a range of 73·2° to 86·0°, the peak occurring in the month of November. Air temperatures when comparing covered and uncovered vehicles on succeeding sampling days were not identical, but the mean temperature for the sampling period was slightly higher on the days when covered vehicles were examined; this provided somewhat severer testing conditions.

TABLE 9

Mean Milk Temperature According to Position of Cans (All Vehicles)

Vehicle	Construction	Inside Position				Outside Position			
		No. of Cans	At Farm Gate (°F)	On Factory Platform (°F)	Increase (°F)	No. of Cans	At Farm Gate (°F)	On Factory Platform (°F)	Increase (°F)
A	Open	83	58·3	66·5	8·2 ± 0·65	164	57·2	68·8	11·6 ± 0·48
	Closed	82	58·0	63·5	5·5 ± 0·47	165	57·3	64·8	7·5 ± 0·38
B	Partially Closed ..	126	58·7	65·2	6·5 ± 0·58	209	56·6	66·9	10·3 ± 0·61
	Closed	126	59·2	63·9	4·7 ± 0·53	209	56·3	64·2	7·9 ± 0·48
C	Partially Closed ..	113	62·1	67·0	4·9 ± 0·52	190	58·9	67·9	9·0 ± 0·61
D	Open	31	59·2	65·2	6·0 ± 1·20	71	57·4	66·7	9·3 ± 1·11
E	Closed	31	53·9	60·6	6·7 ± 0·92	71	55·7	63·2	7·5 ± 0·76

TABLE 10

Milk Temperature Increase (°F) in Open and Closed Vehicles Standing for 1–1½ Hours

Position of Cans	Construction	No. of Cans	Temperature on Arrival (°F)	Temperature at Tip (°F)	Temperature Increase (°F)
Inside ..	Closed ..	12	61·2	61·8	0·6
	Open ..	9	59·2	60·8	1·6
Outside ..	Closed ..	24	63·4	64·2	0·8
	Open ..	18	67·4	68·8	1·4
All Cans		63	63·5	64·6	1·1

TABLE 11

Air Temperature (°F) at 9.00 a.m. on Collection Days for all Vehicles

Month	Mean Air Temperature (°F)							Mean Monthly Air Temperature (°F)
	Vehicle A		Vehicle B		Vehicle C	Vehicle D	Vehicle E	
	Open	Closed	Partially Closed	Closed	Partially Closed	Open	Closed	
October	72	77	75	77	71	..	..	74·4
	78	75	78	76	83	78	80	78·3
November	82	86	81	82	73	82	82	81·1
	92	86	87	85	82	88	82	86·0
December	86	82	82	84	74	88	89	83·6
	76	86	84	86	80	89	87	84·0
January	84	81	82	87	81	..	..	83·0
February	84	86	83	84	82	..	..	83·8
	78	75	79	75	73	..	..	76·0
March	78	80	80	82	80	..	..	80·0
	70	74	74	78	70	..	..	73·2
Mean Trial Air Temperature (°F) ..	80·0	80·7	80·5	81·5	77·1	85·0	84·0	80·7

(f) Dust Contamination

An examination of cans for dust contamination when transported in sealed vehicles indicated that the entry of dust from the rear of the vehicle could reach serious proportions unless the protective covering was close fitting. On those collection days when a rear flap was not used, heavy dust deposits entered and settled on the last 2–4 rows of cans. This was particularly evident for trips with closed Vehicles A1 and B1 but not so severe with Vehicle E. Dust entered as the vehicles slowed to a standstill for can collection. However, when the rear flap was in position contamination was only slight. A loss in freedom of movement for the driver during loading was apparent where completely enclosed vehicles were operating. The accepted practice of loading vehicles from the rear could require modification where complete enclosure was adopted.

Vehicle B, which during normal collection was partially enclosed and therefore permitted a stream of air to pass above the cans in the top tier, was not contaminated to any marked degree.

IV. DISCUSSION

While initial bacterial contamination and subsequent development of such organisms under the conditions of temperature and storage of the farm exert the major influence on milk quality, the continuation of undesirable time/temperature storage conditions during transit can be important. The results obtained in this investigation showed:—

(1) Milk cooling methods on the farm as indicated by pick-up temperatures were variable.

(2) Temperatures which prevailed in milk during transit coincided with the critical level for quality deterioration.

(3) Temperature increase was less when the superstructure of the transport vehicle was modified to minimize air movement around the cans during transit.

(a) Farm Temperature

Of the 1671 cans examined, the percentages in the temperature groupings were—

Temperature Range (°F)	Percentage of Sample
50 and below . .	30·8
51 to 60	27·6
61 to 70	28·0
71 to 80	11·1
81 and over . .	2·5

Difficulty was experienced in obtaining a proportional number of cans in the "81 and over" group.

As milk temperatures below 70°F are only possible on most days under Queensland summer conditions by mechanical refrigeration, these results indicated that 86·4 per cent. of all samples had been subjected to such cooling. There was, however, an even distribution of cans in the temperature groupings from "below 50 to 70°", suggesting a wide variation in the effective utilization of cooling.

The incidence of 13·6 per cent. of cans with temperatures in excess of 70° suggested there was a group of producers whose production methods required revision if quality deterioration prior to arrival at the factory was to be minimized.

(b) Optimum Temperature Level

Smythe (1945), Morton and Vincent (1949) and Vincent (1952) reported that deterioration in milk quality as measured by the methylene blue test commences at 50°F and proceeds at an increasing rate as temperatures rise to 85–90°F. A second factor, the time of storage at the particular temperature level, was also related to quality deterioration. For 4 hours' storage, Vincent (1952) listed the following fall in reduction time of the methylene blue test based on (1) Smythe's investigations and (2) prediction from regression equations of Morton and Vincent.

Storage Temperature		Fall in Reduction Time (¼ hr units) 4 hours' storage	
°C	°F	Smythe	Morton and Vincent
10	50	−0·3	1·2
15	59	1·0	3·3
20	68	4·4	5·7
25	77	7·2	8·1
30	86	10·6	10·6

Smythe also reported that as the storage temperature increased the rate of deterioration (fall in reduction time) was greater in good quality milks than in milks of inferior quality. Furthermore, this rate of deterioration with temperature increased as storage time was prolonged and such an added deterioration was greater when milk quality was high. However, no correlation was obtained between the initial quality of a milk and the effect of storage time.

Bakalor (1946) stated that at milk temperatures above 60°F quality deterioration is of serious proportions.

The mean milk temperature at the farm gate obtained in this investigation ranged from 55° to 60°, at which temperature rapid quality deterioration is initiated. A total of 69·2 per cent. of cans exhibited initial temperatures in excess of 50°. The onset of spoilage would be of greater significance in those milks loaded first onto vehicles, such milk being of a longer post-cooling age before processing than milk collected towards the end of the route. In addition, this milk also approaches more closely to atmospheric temperatures during transit, as evidenced by calculations based on the rate of heating ("k" factor). For a milk with an initial temperature of 50°, transported 40 miles to the processing factory in a vehicle of conventional slat construction under a mean atmospheric temperature of 80°, using a heating constant value (k) of 0·021 it is estimated that the temperature on arrival at the factory platform would approximate 67·1°. In a vehicle completely covered the final temperature calculated using a constant of ·011 would approximate 60·7°. This factor is a guide to general conditions rather than a specific can constant because of the indeterminate influence of can neighbours. This influence of surrounding cans on temperature changes during transit raises the issue of whether a farmer supplying milk of high temperature should be permitted to benefit in terms of quality because his milk is adjacent to refrigerated supplies. The temperature decreases obtained in 9·2 per cent. of all cans examined indicates that such benefits do arise.

As with distance, can positioning was also found to influence the final temperature level of milk. Temperature increases in individual cans exhibited a wide fluctuation from "greater than 25°" to "less than zero" (temperature decrease). An examination of Table 7 reveals that a greater percentage of milk (23·1) in outside cans exhibited temperature increases in excess of 14° than did milk from cans in the inside position (10·6). This suggests that it is with individual cans that the influence of can position on temperature assumes importance. If transport conditions can be so arranged to afford added protection to such individual supplies, then modifications are warranted.

(c) Influence of Covering on Milk Temperature

It is considered that one of the prime purposes of covering vehicles should be to prevent the passage of hot air through the vehicle while in transit, thus minimizing the increase in temperature of those milks which had been previously cooled on the farm.

Jenkins *et al.* (1949) reported an average temperature increase of 2°F during transit in open vehicles and an increase of only 1°F when the vehicles were protected with tarpaulins. Results obtained in this Queensland investigation indicated "all can" mean increases ranged from 6·7 to 10·4°F in vehicles differing in construction. The greater percentage of cans in the lower initial temperature ranges (58·4 per cent. below 61°F) in this investigation, compared with 36 per cent. of cans in this range in the English trials, could account for this larger temperature increase.

McWhirter (1956) reported that "experiments revealed there is no rise in temperature of cream in summer weather when the cans are not covered provided that the vehicle is not stationary for longer than the time necessary for pick-up, i.e. 1–2 mins." No temperature results of these experiments were reported.

In Vehicle A it was possible to reduce the extent of temperature increase during transit between the open conventional slat superstructure and the completely sealed construction from 10·4 to 6·9°, a reduction of 3·5°. With modifications to Vehicle B, when a partially enclosed vehicle was completely sealed to prevent air movement around the cans, increases were reduced from a mean of 8·8° to 6·7°, a decrease of 2·1°.

Close agreement was obtained between temperature increase and final milk temperature for Vehicles A1 and B1 with completely sealed construction, indicating that enclosure with a removable canvas canopy provided protection similar to that obtained when the superstructure was composed of timber.

As indicated in Table 1, less protection was afforded to cans in Vehicle C, where only partial closing was provided, than to cans in Vehicle B (partially closed). Final mean milk temperature of 67·6° in the former vehicle in comparison with 66.2° for Vehicle B, when initial mean milk temperature was 2·7° higher and atmospheric temperature lower, suggests that the protection afforded when sides are timbered to can shoulder height is not as effective as when sides are sealed to protect the complete can. In this latter construction (Vehicle B), air movement was directed largely along the lower side of the top canopy and above the surface of the can.

Initial mean milk temperatures for Vehicle D (open) and Vehicle E (closed) were 58·0° and 55·2° respectively. This initial variation made it difficult to obtain a satisfactory comparison of the effectiveness of covering. Final mean temperatures, however, suggest that some benefit was obtained with milk in Vehicle E from the additional protection provided.

(d) Influence of Covering on Dust Contamination

McWhirter (1956) indicated "the incidence of dust from unsealed roads settling on cans is greater when a canopy type cover is used and is at a minimum when no cover at all is employed."

Results obtained in this investigation indicated that when movement of air through the vehicle was restricted the entry of dust from unsealed roadways increased. It was possible, however, with the provision of a canvas rear flap to prevent serious dust contamination of can surfaces. These results show that where enclosure of superstructure is recommended provision must be made also for sealing of the rear of the vehicle. Alternatively, if some air movement is considered desirable to provide a positive internal air pressure, construction should be so modified as to direct the air flow immediately below the protective canopy and not around the can surface.

(e) Aesthetic Considerations in Covering

The viewpoint of providing the maximum protection possible to a perishable product deserves consideration when high standards of production and storage are demanded of producers. It can be argued that for transport under subtropical weather conditions complete protection should be provided.

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REFERENCES

ABRAHAM, S., and OUTWATER, C. H. (1944).—The effects of farm cooling methods and transportation on the temperature of night's milk. *J. Milk Tech.* 7: 78-84.

BAKALOR, S. (1946).—Temperature of milk on arrival at the city dairy. *Fmg S.Afr.* 21: 413-6.

BRANDSMA, L., and HUNT, L. L. (1959).—Proper use of "in-can" mechanical coolers for manufacturing type milk. *J. Milk Food Tech.* 22: 304-9.

BRINDLEY, M., SCARLETT, C. A., and ROWLANDS, A. (1946).—Effect of shade on milk temperature. *Agriculture* 53: 123-4.

CRONSHAW, H. B. (1947).—"Dairy Information." (Dairy Industries Ltd: London).

HARVEY, W. C., and HILL, H. (1946).—"Milk Production and Control." 2nd Ed. (H. K. Lewis and Co.: London).

JENKINS, I., REEVE, E. M., and PROVAN, A. L. (1949).—Change of temperature of milk in transit from farm to factory. *J. Soc. Dairy Tech.* 3: 182-6.

KELLY, E., and CLEMENT, C. E. (1931).—"Market Milk." 2nd Ed. (J. Wiley and Son: New York).

McDOWALL, F. H. (1953).—"The Buttermaker's Manual." Vol. 1. (New Zealand University Press : Wellington).

McWHIRTER, G. M. (1956).—Collection of cream. *Proc. 14th Int. Dairy Congr.* 1: 270-6.

PESK, C. M. (1944).—The influence of temperature in open and closed truck hauling. *Amer. Butter Rev.* 5: 274-6.

ROADHOUSE, C. L., and HENDERSON, J. L. (1941).—"The Market Milk Industry." 1st Ed. (McGraw-Hill: New York).

SCHUBERT, W. F. (1956).—Temperature more important than distance in milk quality. *Qd Agric. J.* 81: 653-4.

SMYTHE, V. R. (1945).—Studies on the effects of transport and storage on the bacteriological quality of raw milk. Part 2. The effect of the milk can on the methylene blue reduction time. *Qd J. Agric. Sci.* 2: 128-56.

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