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Cost Comparisons for Carbon Dioxide and Mechanical Multi-Temperature Refrigeration Systems On Highway Trailers*

by

K. E. Hoke
Agricultural Marketing Specialist
U.S. Department of Agriculture
Office of Transportation
International Division, Export Services Branch
Washington, D.C.

F. K. Buxton
U.S. Department of Agriculture
Office of Transportation
Domestic Division, Domestic Services Branch
Washington, D.C.

Abstract

Liquid carbon dioxide refrigeration offers a simple, reliable alternative to mechanical transport refrigeration for food delivery trailers operated in an upper midwestern area that could be cost effective when the refrigerant's cost is \$87 or less per ton. Operating and ownership costs were compared for both systems. Under the conditions of the study, a carbon dioxide system was more economical than a mechanical refrigeration system when the cost of the liquid carbon dioxide was \$87 per ton or less. The study indicated that a fleet of at least ten carbon dioxide refrigerated units is needed to justify use of a storage tank that can accept a 20-ton delivery of liquid carbon dioxide.

Introduction

The need to deliver economically frozen foods, fresh meats, fruits and vegetables and dry groceries to convenience stores, institutional food service operations and restaurants in a

single vehicle has led to the development of multi-temperature refrigerated highway trailers. Distributors servicing the fast food and dairy industries have been major innovators and users of multi-temperature transport equipment employing new transport refrigeration technologies.

The technology of using cryogenics to maintain temperature control in food delivery vehicles is not new. The U.S. Department of Agriculture (USDA) in cooperation with cryogenic suppliers and industry has conducted research and developed technologies needed to apply cryogenic refrigeration to the food transportation industry since the early 1960s [1,2,3]. Karitas [4] recommended the use of multi-temperature trucks for institutional food delivery systems. His studies show that the use of single compartment trucks resulted in the highest food delivery cost.

In 1984-85, the USDA's Office of Transportation conducted field tests in cooperation

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with a food distributor to evaluate the performance of mechanical and cryogenic transport refrigeration systems in multi-temperature highway trailers [5]. The cryogenic refrigeration system, based on the system patented by Nielsen [6], injected carbon dioxide directly into each trailer compartment upon thermostatic demand. A sketch of the liquid carbon dioxide food delivery trailer is presented in Figure 1. The liquid carbon dioxide was carried in a 1000-pound supply tank mounted under the trailer behind the landing gear. Thermostats were set to maintain 0°F in the forward, 35°F in the middle compartments. No refrigeration was provided in the rear trailer compartment where dry groceries were carried. The 45-foot polyurethane foam insulated trailers had thermal ratings of 86 BTUs per hour per degree F. The mechanical refrigeration unit consisted of a direct expansion evaporator located in each compartment. The refrigeration capacity for the front, middle and rear compartments was 12,000, 9,000 and 9,000 BTUs per hour, respectively. Bulkheads separating the trailer compartments were constructed of two six-inch polyurethane foam panels covered with nylon material. Bulkheads were held in place with retaining bars locked into the trailer's sidewall channels.

Typically, trailer loading began around 2:00 PM with palletized frozen items in the front compartment, followed by fresh products in the middle, and dry groceries in the rear. The mechanical refrigeration unit was started upon completion of loading the frozen items and positioning the bulkhead separating the frozen-fresh compartments. The cryogenic refrigeration unit was started after the frozen items and fresh products were loaded and the respective bulkheads positioned. Loading was usually completed by 6:00 PM.

Before being dispatched at about 9:00 PM the truck driver and his assistant reviewed the orders and special instructions for each store on their designated route. Each delivery route included six to eight stops within a specified geographical area. The trucks returned to the distribution warehouse by 9:00 AM the next morning.

Results of the cooperative study showed that the cryogenic refrigeration system rapidly obtained the set temperature in each trailer compartment after door openings at stops to unload and maintained the set temperatures along the route within a very narrow range. Figure 2 depicts the air temperatures during a food delivery to a fast food store in a carbon

dioxide refrigerated trailer. Each door opening is characterized with a sharp rise in temperature followed by a rapid lowering when the food delivery is complete and the unit is turned on. Since no refrigeration is required for the delivery of dry groceries, the air temperature in the dry grocery compartment parallels the ambient air temperature. Temperature recovery rate is a critical factor in the delivery of frozen food items, particularly ice cream and prepared food items.

The temperature recovery rate within each mechanical trailer compartment after door openings was considerably slower than the cryogenic system. Also, the mechanical multi-temperature refrigeration system noise level was higher than the cryogenic system. For night deliveries to stores located near residential areas, local ordinances require low noise levels. Mechanical refrigeration units are shut off during delivery. Cryogenic systems have little operating noise.

The economic feasibility of using a cryogenic transport refrigeration system in multi-temperature highway trailers was not included in the performance studies conducted in 1984-85. Purpose of the study was to compare the costs between cryogenic and mechanical multi-temperature transport refrigeration systems used to delivery food products.

Methodology

Cost information for 1987 was obtained from the same food distribution company that cooperated in the 1984-85 performance comparisons. The cooperator's cryogenic refrigeration operation is being run on an experimental basis to determine the operational and cost characteristics of the system. The distributor delivers primarily to fast food restaurants, but also to a few schools, colleges, hotels and hospitals. Operating costs were obtained from the food distributor's accounting records for 25 refrigerated highway trailers (21 mechanical and 4 cryogenic trailers) over the 1987 calendar year. Values on the purchase price, salvage value, useful life, and interest rate for the trailers and refrigeration units as provided by the cooperator are shown in Table 1. Interest costs for trailers and refrigeration units are computed by dividing purchase price less the salvage value by two. This approximates the cooperator's average equity in the refrigeration units and trailers during the "useful equipment" life. The cooperator's average equity plus a salvage value was multiplied by the current interest rate at the end of 1987 to estimate the interest cost. The

Figure 1

A Liquid Carbon Dioxide Multi-Temperature Food Delivery Vehicle

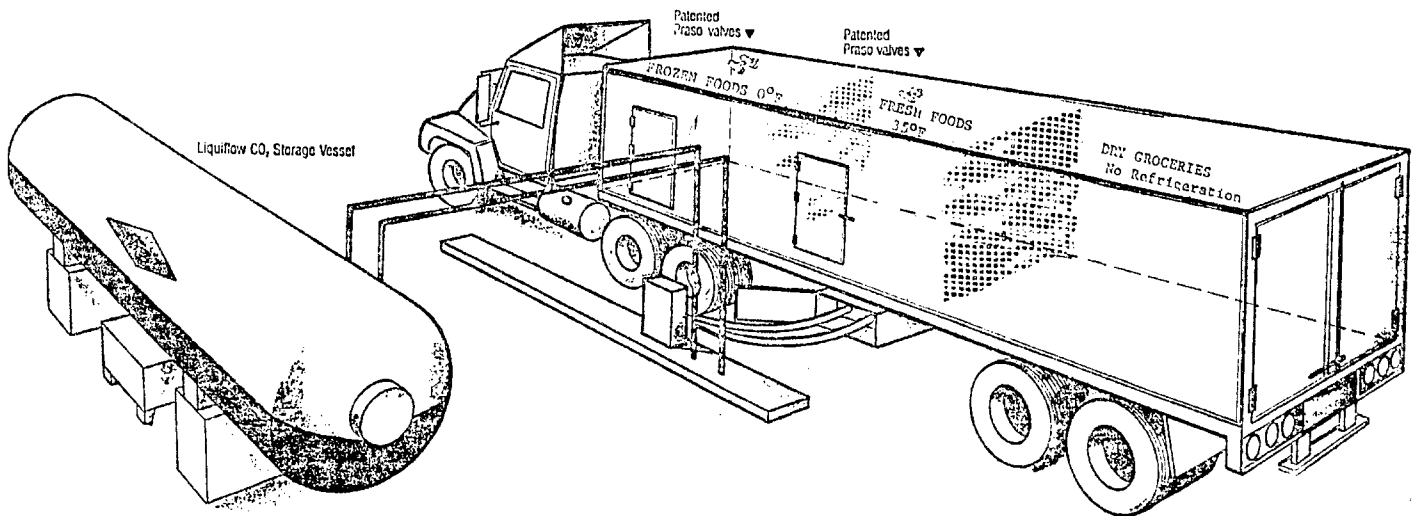


FIGURE 2 - AIR TEMPERATURES FOR AMBIENT, DRY GROCERIES, FRESH AND FROZEN FOODS
COMPARTMENTS IN A MULTI-TEMPERATURE LIQUID CO₂ REFRIGERATED TRAILER

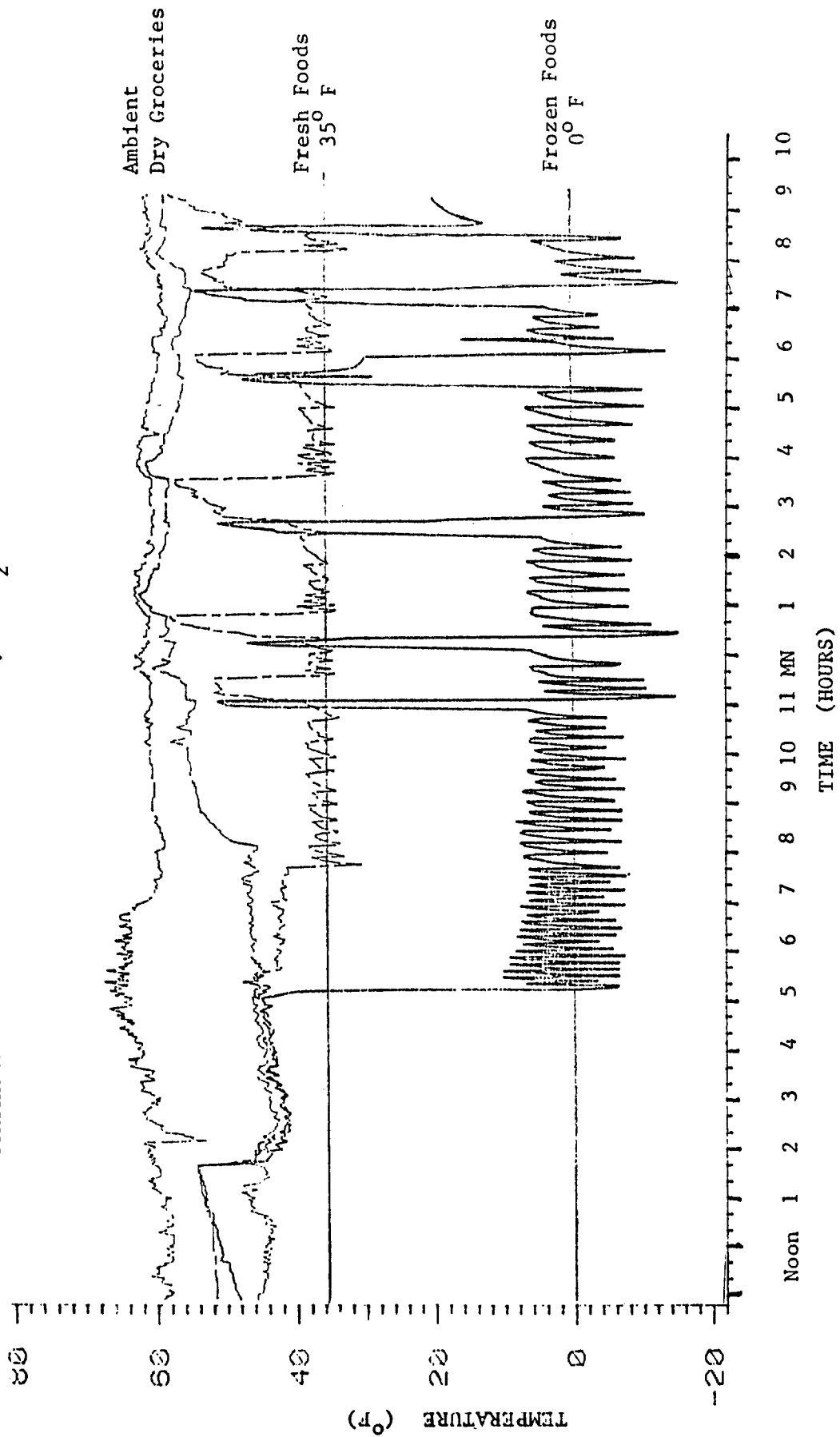


Table 1

**Variables Used to Compute Interest and Depreciation
Included in Ownership Cost for the Three-compartment Refrigerated Trailers**

Item	Purchase Price	Salvage Value	Useful Life (Years)	Interest Per Year
Trailer	\$32,000	\$2,000	10	11.5%
CO ₂ Unit	\$10,800	\$3,000	10	11.5%
Mechanical Unit	\$17,200	\$250	7	11.5%

Table 2

**1987 Total Costs Per Trailer for Fuel, Maintenance and Ownership
For Carbon Dioxide and Mechanical Refrigerated Multi-compartment Highway Trailers**

----- Per Trailer -----		
Item	Cryogenic	Mechanical
Fuel:		
CO ₂ - 10 months @ \$120/ton and 2 months @ \$80/ton	\$5,923	
Fuel oil, No. 2 @ \$1.10/gal.		\$2,123
Maintenance:		
Trailer	\$1,737	\$1,754
Refrigeration System	\$ 315	\$1,595
Ownership Cost:		
Trailer - Depreciation & Interest @ 11.5%	\$4,955	\$4,955
Refrigeration System - Depreciation & Interest @ 11.5%	\$1,574	\$3,427
Storage Tank & Pump (20 ton) - Rental Cost	\$ 990	
TOTAL COST:	\$15,494	\$13,854

straight line depreciation method was used to determine costs by expensing the purchase price for the trailers and refrigeration units minus the salvage values over the useful life of the equipment. Variables used are shown in Table 1.

During winter operation in cold climates, the carbon dioxide trailers are heated in the non-frozen compartments to prevent foods from freezing. The costs reported herein include the costs associated with the purchase, operation and maintenance of a heating unit installed. The mechanical units were equipped with heating provisions.

Results and Discussion

A comparison of the operating and ownership costs for cryogenic and mechanical refrigeration systems used in three-compartment highway trailers during 1987 is shown in Table 2, and lists the cost of fuel, maintenance, interest, depreciation, and storage tank rental. The greatest cost difference between the carbon dioxide refrigeration system and the mechanical system was in the ownership cost which averaged \$1,853 lower for the carbon dioxide units. Refrigeration maintenance cost for the carbon dioxide units also showed a substantial savings of \$1,280 per unit.

In this particular comparison, actual total cost for the carbon dioxide refrigeration system was \$1,640 per unit higher than for the mechanical refrigeration system. This was largely because the carbon dioxide price paid by the cooperator was \$120 per ton for the first ten months of the year and \$80 per ton for the remainder. Had the carbon dioxide price been \$80 per ton for the entire year, total cost would have been \$358 less per trailer than for the mechanical unit. See the section on price scenarios for carbon dioxide for the effect of different price levels on total operating cost.

The carbon dioxide refrigeration system because of the few moving parts was less costly (\$1,280 per unit) to maintain and repair. Trailer maintenance costs were about the same for both refrigerated systems. Rental of the carbon dioxide storage tank (20-ton capacity) and transfer pump cost averaged \$990 per trailer.

Carbon dioxide fuel costs vary considerably throughout the United States according to demand and proximity to supply. The price the food distributor pays for carbon dioxide is a major consideration when deciding to invest in the carbon dioxide refrigeration sys-

tem. Also, the geographical location determines carbon dioxide consumption--food distributors located in the cooler climates will not use as much of a cryogenic refrigerant as will food distributors located in warmer climates. These factors are discussed in the following sections.

In Table 2 the actual total yearly costs were obtained from the food distributor's 1987 records. Maintenance costs for the cryogenic and mechanical trailers and refrigeration units are the total cost for labor, parts, lubricants, miscellaneous items and taxes.

Price Scenarios for Carbon Dioxide

Four price scenarios were developed to estimate cost of the system based on the purchase price of the carbon dioxide. The prices used for carbon dioxide were \$60, \$80, \$100 and \$120 per ton. Each of four carbon dioxide prices were combined with the cooperator's ownership and operating costs for the year 1987 and are shown in Table 3. When liquid carbon dioxide is priced at \$120 per ton the yearly total cost per trailer would be \$1,679 above the cost of operating a conventional mechanical transport refrigeration unit. At \$100 per ton the cost difference is lowered to \$664 per trailer. At \$80 per ton, the liquid carbon dioxide unit total operating cost is \$350 lower than the cost of owning and operating a mechanical transport refrigeration unit. At \$60 per ton the total cost for operating the carbon dioxide unit is estimated at \$1,363 lower than a comparable mechanical refrigeration unit. This illustrates that the purchase price of the liquid carbon dioxide is a major factor in determining whether a carbon dioxide system is cost competitive with a conventional mechanical system. Figure 3 also shows that the costs for a carbon dioxide refrigeration system would be lower than a mechanical refrigeration system when the price of the liquid carbon dioxide is at or below \$87 per ton.

The findings are based on the carbon dioxide fuel consumption incurred by a single food distributor located in the northern midwest United States. The study does not reflect operating costs of food distributors located in warmer regions of the nation. The mean quarterly temperatures and corresponding rate of carbon dioxide fuel consumption shown in Figure 4 illustrate the influence of climatic conditions on carbon dioxide consumption. Additional study and data would be required before conclusions could be made on operating cryogenic transport refrigeration units in warmer regions.

Table 3

**Projected Trailer Cost Comparison Between Carbon Dioxide (CO₂) and
Mechanical Refrigeration Systems in Multi-Compartment Highway Trailers
At Different CO₂ Purchase Prices**

	----- Purchase Price of CO ₂ /Ton -----			
	\$ 120	\$ 100	\$ 80	\$ 60
Cost CO ₂ per year*	\$ 6,088	\$ 5,073	\$ 4,059	\$ 3,046
Other Cost**	<u>9,445</u>	<u>9,445</u>	<u>9,445</u>	<u>9,445</u>
Total Cost CO ₂	15,553	14,518	13,504	12,491
Total Cost Mechanical**	13,854	13,854	13,854	13,854
Cost Difference	+1,679	+ 664	- 350	-1,363

* Based on Co-operator's 1987 consumption

** Cooperator's 1987 maintenance and ownership cost

Table 4

**Projected Total Fuel and Storage Tank Costs per Trailer
For 10 and 20 Trailers at Three Liquid Carbon Dioxide Prices
Using a 30- to 33-ton Horizontal Storage Tank**

Number of Trailers	Price of CO ₂ /ton	Total Annual Cost of CO ₂	Storage Tank Yearly Rental	CO ₂ & Tank Rental Cost	Cost per Trailer
10	\$60	\$30,000	\$12,600	\$42,600	\$4,260
10	\$80	\$40,000	\$12,600	\$52,600	\$5,260
10	\$100	\$50,000	\$12,600	\$62,600	\$6,260
20	\$60	\$60,000	\$12,600	\$72,600	\$3,630
20	\$80	\$80,000	\$12,600	\$92,600	\$4,630
20	\$100	\$100,000	\$12,600	\$112,600	\$5,630

Figure 3

**Per Trailer Cost Comparison for Multi-Temperature Carbon Dioxide¹⁰
And Mechanical Refrigerated Highway Trailers, 1987**

(Based on Selected CO₂ Price Scenarios)

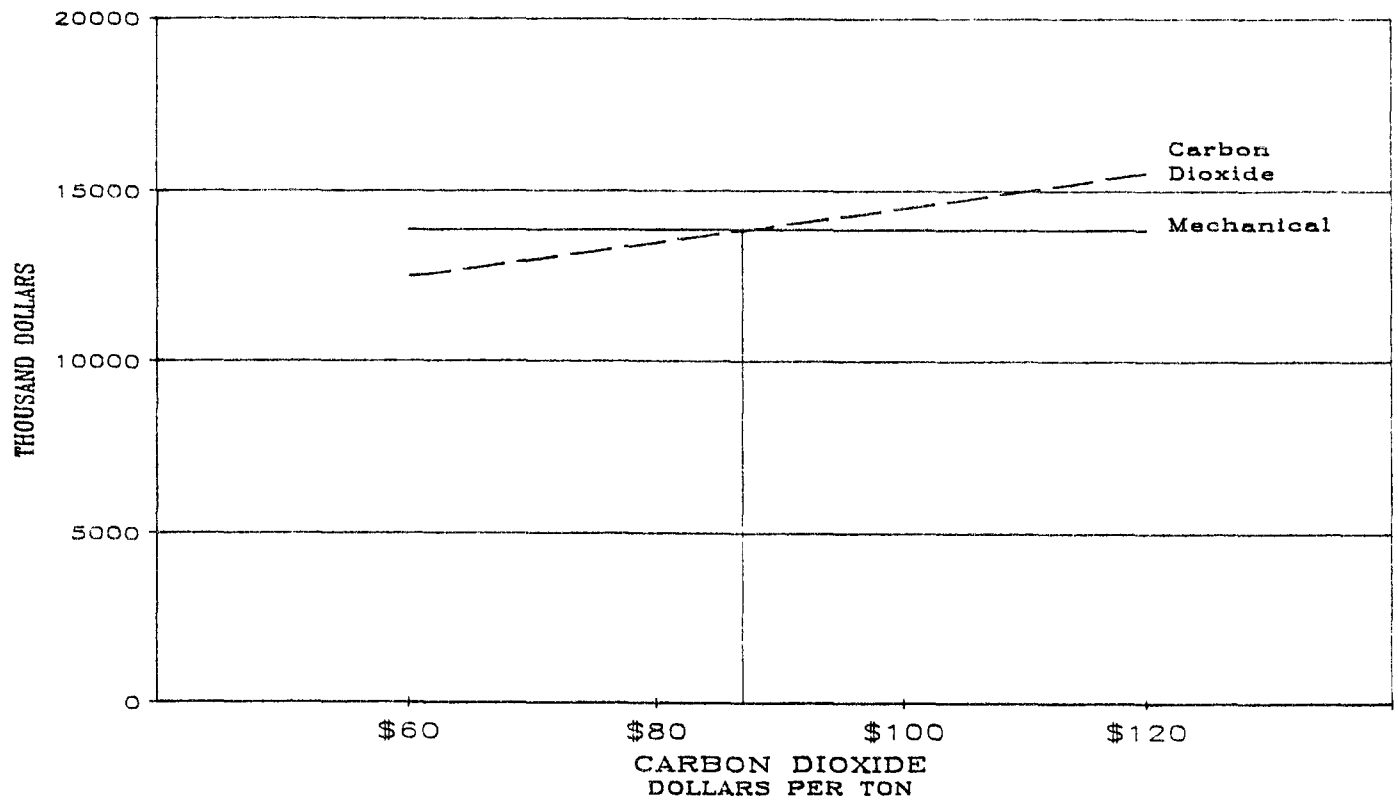
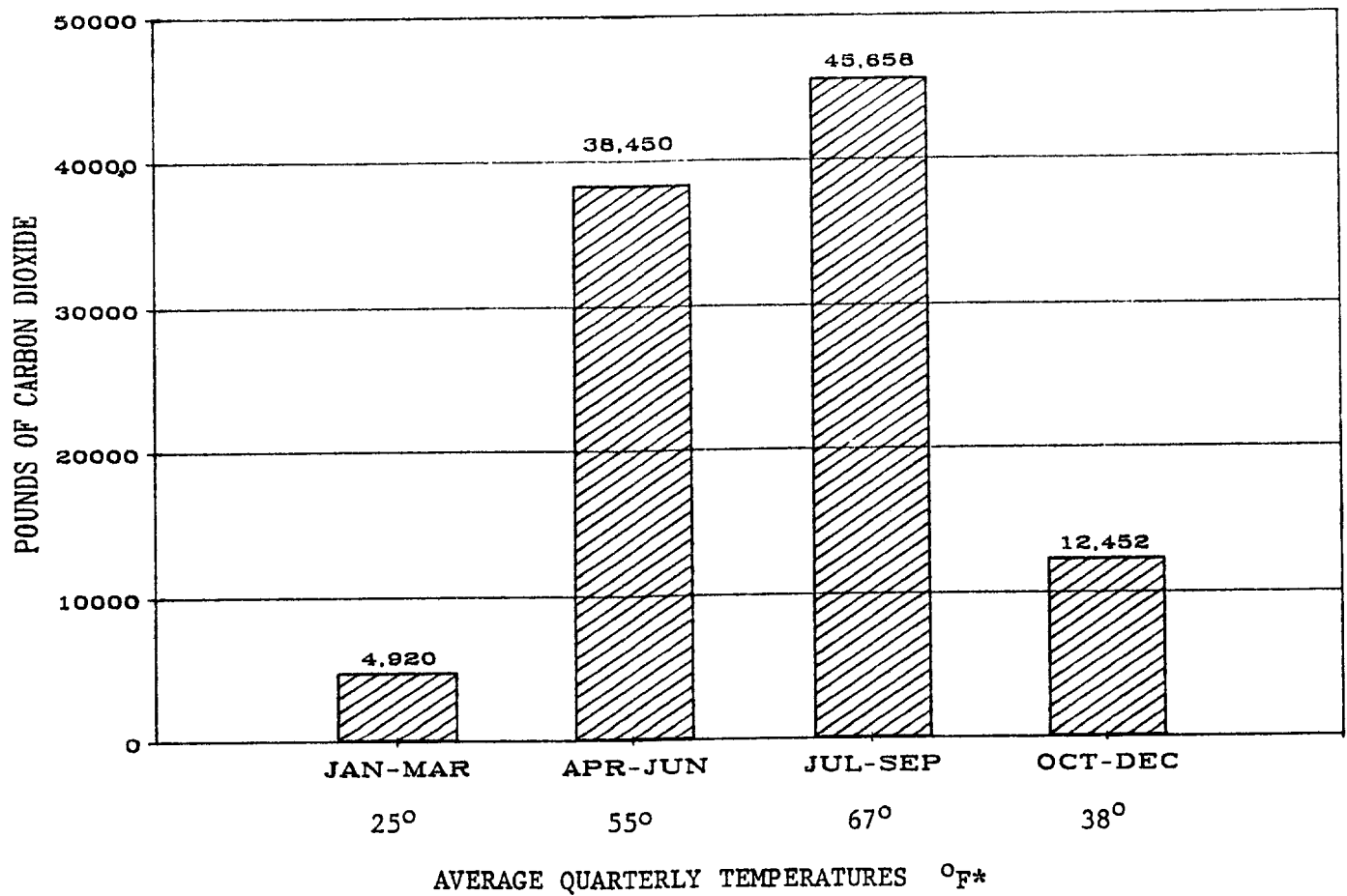


Figure 4

**Seasonal Consumption of CO₂ by a Multi-Temperature Food Delivery Trailer
And Average Quarterly Temperature, 1987**



* Average quarterly temperatures for geographic area where study was conducted. Source: "The World Almanac Book of Facts, 1988"

Storage Tank Size

The number of units being serviced is a major factor in tank size selection. A trailer truck load of liquid carbon dioxide is 20 tons. A storage tank capacity of 30 to 34 tons horizontal or 33 tons vertical needs to be installed for the user to be able to take full trailer load deliveries and thus obtain the lowest carbon dioxide price. Vertical storage tanks can be used when there is a minimum amount of space available at a facility. At 1987 monthly rental prices a 30- to 33-ton horizontal storage tank and pressure vaporizer cost \$1,050, and the vertical storage tank unit rent was \$1,150 per month.

Under the conditions of this study, it was determined that a fleet size of ten or more cryogenic refrigeration units would be needed to justify the rental of a 30- to 33-ton capacity tank. A horizontal storage tank this size rented for \$12,600 per year in 1987. Table 4 projects the storage tank rental cost per trailer and other costs factors associated with operating a fleet of either ten or twenty cryogenic refrigerated trailers, when liquid carbon dioxide is priced at \$60, \$80, and \$100 per ton. The average unit operating cost decreases considerably with an increase in fleet size. For example, average annual operating costs would decrease \$630 per unit for a twenty-trailer fleet versus a ten-trailer fleet.

The food distributor had a twenty-ton liquid carbon dioxide storage tank. This storage tank does not have the storage capacity to accept full truck load quantities of carbon dioxide. However, it is sufficient to service the four trailers presently contained in the cooperator's fleet.

Conclusions

1. Based on the conditions of this study, when carbon dioxide costs less than \$87 per ton, a carbon dioxide refrigeration system is a cost effective alternative to diesel/mechanical in multi-temperature food delivery vehicles.

2. To purchase liquid carbon dioxide at the lowest price, a twenty-ton delivery (full trailer load) needs to be ordered. To store full loads on the premises, the food distributor needs a storage tank of 30 to 33 tons. Such a tank will accommodate at least ten transport refrigeration units. Additional fleet units would further lower the cost of operating carbon dioxide units.

3. Maintenance and ownership costs were considerably lower for the carbon dioxide refrigeration system than for the mechanical transport refrigeration unit.

4. Whether carbon dioxide refrigeration would be economical in other areas of the United States would have to be determined through additional cost studies designed to evaluate: (1) climatic conditions, (2) purchase price of the carbon dioxide, and (3) trailer fleet size.

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