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Transportation

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Perishable products are moved from the location of production to the consumer in a variety of transportation systems. In North America, refrigerated rail service was used extensively in the past. Now, most products are moved by refrigerated highway trucks. Most international trade into and out of North America utilizes refrigerated marine containers or ships. Airplanes that do not have temperature control capability are used for limited quantities of high-value commodities.

The goal of transportation is to move perishable products with a minimum loss of quality. Most transportation equipment controls air temperature around the product. Special equipment is sometimes available to produce a modified or controlled atmospheric (gas) composition around the product. Humidity and vibration control equipment are also used on some vehicles.

HIGHWAY TRUCKS

Large refrigerated highway vehicles are usually semi trailers. A powered tractor provides motive power and support for the front of the trailer (fig. 20.1). Trailers are sometimes placed on rail cars for a portion of the trip and then transported from a central rail location to the final destination with a highway tractor. This is sometimes referred to as a "trailer on flat car" (TOFC) shipment system. In North America refrigerated highway trailers are used for trips lasting from about 1 to 5 days.

The trailer has a self-contained engine-driven refrigeration system that provides conditioned air to the insulated load space. Most new trailers in the United States have an outside width of 2.6 m (102 in) and can be purchased in exterior lengths from 12.2 to 16.2 m (40 to 53 ft). Most new trailers are 16.2 m (53 ft) long. Interior volume ranges from 70 to 100m^3 (2,500 to 3,500 ft^3). The gross vehicle weight (including tractor) can not exceed 36,288 kg (80,000 lb) in the United States and individual axles also have weight limit to ensure a fairly uniform weight distribution in the vehicle. Most semi trailers have a load capacity of about 18,100 to 20,400 kg (40,000 to 45,000 lb).

Refrigeration capacity of new units is typically 12.3 to 16.4 kW (3.5 to 4.7 tons). The unit can provide heat when the trailer is operated in ambient conditions colder than the set point temperature. The refrigeration unit is located on the top front of the trailer and provides refrigerated air to an air chute in the top of the trailer (fig. 20.2). Product should be loaded and secured to provide an air space around the load (fig. 20.3). This allows the refrigerated air to flow between the load and the walls, underneath the product, and finally return to the refrigeration unit through a bulkhead in the front of the trailer. This design allows the refrigerated air to intercept this heat before it affects product temperature. Top-delivery refrigeration systems do not have enough airflow to dependably remove product heat from most commodities, and they should be cooled to transit temperature before loading.

The majority of the heat that the refrigeration unit removes comes from heat conducted across the walls and from air leaking into the trailer. If product is not center-loaded it will be warmed by contact with the walls. A series of shipments of California strawberries cooled to 1.7°C (35°F) and shipped with thermostats set at that same temperature showed average arrival temperatures in New York of 3.9°C (39°F) for center-loaded fruit and 5°C (41°F) for side-wall-loaded fruit. Warmest berries in center-loaded were 5°C (41°F) and 6.7°C (44°F) for side wall loading.

In the United States, the Refrigerated Transportation Foundation has developed a classification system for the combined insulated trailer and refrigeration unit. Vehicles using this classification system are rated for their ability to effectively transport products in four temperature categories (table 20.1). Metal placards located on the outside and inside of the trailer list the temperature range and other design characteristics of the vehicle. Most perishable fruits, vegetables, and flowers should be shipped in trailers with at least a C35 rating and equipped with an air chute and a front bulkhead.

Relative humidity is usually not controlled in refrigerated trailers. Some equipment manufacturers offer atomizers to add water to the refrigerated air. However, the added humidity reduces fiberboard strength. Acceptable levels of RH are a compromise between minimizing product moisture loss and minimizing damage caused by weakened packages. Product moisture loss can also be reduced by packing product in plastic liners, bags, or consumer-sized packages. These reduce moisture loss while allowing the refrigeration system to operate at lower humidities and protect fiberboard strength.

Atomizers will freeze if air temperature around them is close to 0°C (32°F). This may require that the thermostat be set a little warmer than the optimum for temperate fruits and cool-season vegetables. If products are not particularly sensitive to damage from moisture loss, it may be better to not use humidifiers and set the thermostat as low as possible. Humidification systems may find their best use with chilling sensitive commodities that are shipped at temperatures between 5°C (41°F) and 13°C (55°F).

Highway trailers are not airtight enough to allow their use as a gas barrier for modified or controlled atmosphere handling. Modified atmospheres can be provided through the use of semipermeable films used to form consumer packages or pallet wraps.

During transit some products can be damaged by the constant vibration caused by the road or by a shock caused by the vehicle traveling over a bump or curb. Both of these cause most damage to product loaded directly over axles. Vibration is amplified as it is transmitted through fiberboard boxes, and this causes most damage to product in topmost boxes on a load. Commercially available air ride suspension systems eliminate most of this damage. They cost more than steel spring suspensions but are becoming more commonly available on trailers. Some transport companies require that all of their new equipment have air ride suspension.

Figure 20.1

Refrigerated semi trailer.

Figure 20.2

Refrigeration and airflow system in highway trailer.

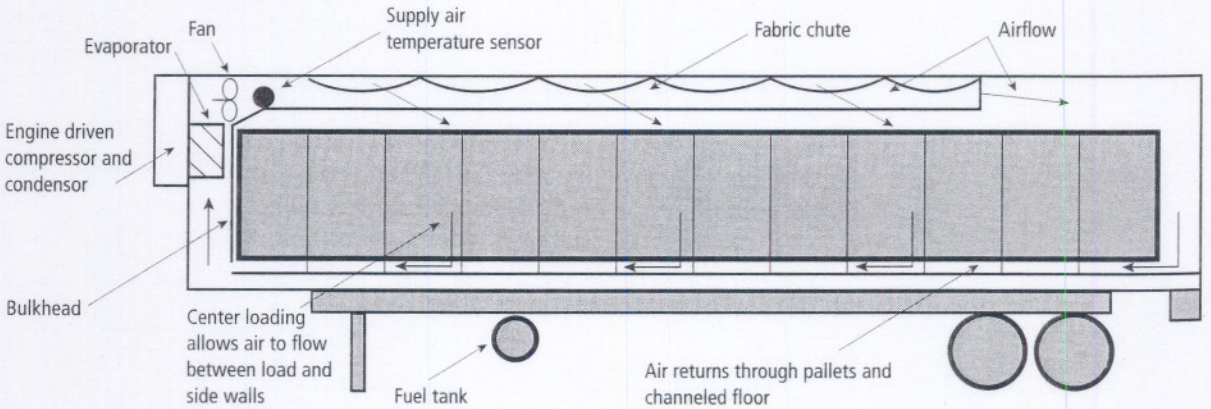


Figure 20.3

Procedures for bracing a center-loaded product in a highway trailer.

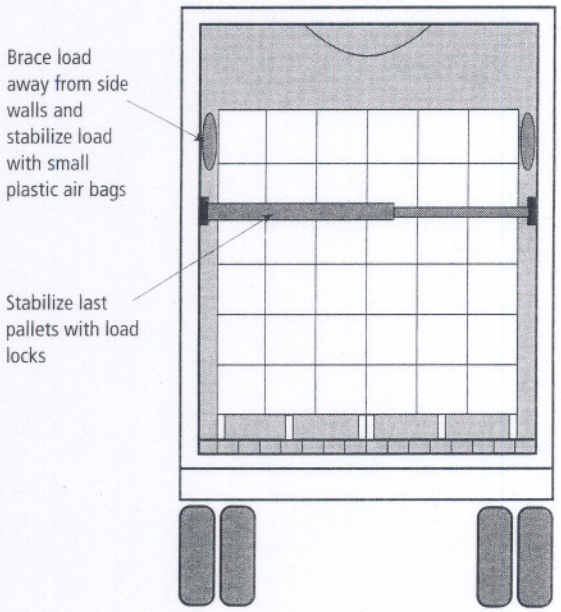


Table 20.1. Refrigerated Transportation Foundation temperature limit ratings for refrigerated trailers

Vehicle rating	Rated minimum temperature	Type of product protection
C65	18°C (65°F)	Controlled temperature
C35	2°C (35°F)	Fresh fruit, vegetables, flowers
F	–18°C (0°F)	Frozen foods
DF	–29°C (–20°F)	Ice cream and frozen foods

They also increase tire life and may reduce vibration damage to the trailer itself. Nearly all long-haul tractors in the United States have air ride suspension for driver comfort, so semi trailers usually have air ride suspension for the axles under the front. Vibration-sensitive product should not be loaded directly over axles suspended on steel springs. Vibration damage can also be reduced by packing product so that it is immobilized.

Over three quarters of the product that leaves California is shipped in loads with mixed products. These loads must be set up so that they are compatible. Use table 20.2 to select compatible produce. The chart divides common fruits and vegetables into four categories. Produce in the same vertical section can be safely held at the same temperature range listed on the top of the section. If produce in different temperature section are mixed, produce quality will be compromised, especially with longer transit times. The greater the difference in recommended temperature between the produces, the greater the potential for quality loss.

Dried vegetables in the top shaded area should not be mixed with any produce below them on the chart. These vegetables should be held in a 50 to 70% RH environment to prevent decay development. Most of the 0° to 2°C (32° to 36°F) vegetables are sensitive to moisture loss and should be held at more than 90% RH or packaged to minimize water loss. All the rest of the vegetables and fruit should be held at 85 to 95% RH.

Ethylene-sensitive vegetables near the top of the chart should not be mixed with ethylene-producing fruits at the bottom of the chart and luffa and ripe tomatoes. If for some reason they must be mixed, ethylene scrubbers may reduce damage. Produce items in the shaded middle of the chart are neither sensitive to ethylene nor are they ethylene producers and can be mixed with the items above or below them in the same temperature section.

Some produce items can exchange odors with other selected produces. See the notes at the bottom of table 20.2 for precautions.

Local refrigerated transport from distribution centers to stores or restaurants is nearly always a mixed load. Products may have widely differing temperature requirements and susceptibility to ethylene and odors. Most products survive this because the trip is short allowing products to be in a compromised environment for only a few hours. If frozen product is also part of the load, then the vehicles often have several compartments. Each compartment is set at a different temperature and each has a separate outside door allowing products to be carried at more ideal temperatures.

Thermostat temperature is set based on a compromise between the relative obvious damage caused by freezing temperatures and the less obvious damage caused by higher-than-recommended temperature. For products that are not chilling sensitive, thermostats are usually set below 4.4°C (40°F) but above 1.7°C (35°F). Newer refrigeration units with supply-air temperature sensing can be set lower than this because the control system is designed to ensure that the coldest temperature in the load, at the air

Table 20.2. Compatible produce for long-distance transport (Produce in the same temperature column can be safely mixed. Ethylene-sensitive vegetables should not be mixed with ethylene-producing fruits and vegetables. Dry vegetables should not be mixed with other fruits and vegetables.)

Produce	Recommended storage and transport temperatures											
	0°–2°C (32°–36°F)			4°–7°C (40°–45°F)		7°–10°C (45°–50°F)			13°–18°C (55°–65°F)			
Dry vegetables	Dry onion[1,3,9]	Garlic							Ginger[5]	Pumpkin	Squash, winter	
Ethylene-sensitive vegetables	Arugula*	Chicory	Mint	Beans, snap, etc.*[10]		Basil*			Potato, early crop*			
	Asparagus	Chinese cabbage	Mushroom*[7]	Cactus leaves		Chayote			Tomato, mature green			
	Belgian endive	Collards*	Mustard greens*	Cucumber*		Eggplant*[5]						
	Bok choy	Cut vegetables	Parsley	Pepper (chili)		Kiwano						
	Broccoflower	Endive	Parsnip	Potato, late crop[1]		Long bean						
	Broccoli*	Escarole	Snow pea*	Southern peas*		Okra						
	Brussels sprouts	Green onion[7]	Spinach*	Tomatillo		Squash, summer*						
	Cabbage[1]	Herbs (not basil)	Sweet pea*			Watermelon						
	Carrot[1,3]	Kailon*	Turnip greens									
	Cauliflower	Kale*	Watercress									
	Celery[1,3,9]	Leek[8]										
	Chard*	Lettuce										
Vegetables (not ethylene sensitive)	Amaranth*	Jerusalem artichoke	Salsify			Calabaza			Cassava			
	Anise	Kohlrabi	Scorzonera			Haricot vert			Jicama			
	Artichoke	Lo bok	Shallot			Pepper, bell[10]			Sweet potato (boniato)			
	Bean sprouts*	Radicchio	Sweet corn [7]			Winged bean			Taro (malanga)			
	Beet	Radish	Swiss chard						Yam			
	Celeriac	Rhubarb [7]	Turnip									
	Daikon	Rutabaga	Waterchestnut									
	Horseradish					Luffa* †			Tomato, ripe* †			
Fruits and melons (very low ethylene producing)	Barbados cherry	Longan		Blood orange[4]		Babaco	Tamarillo		Breadfruit			
	Bitter melon	Loquat		Cactus pear (tuna)		Calamondin*	Tangelo[4]		Canistel			
	Blackberry*	Lychee		Jujube		Carambola	Ugli fruit		Grapefruit, CA, AZ[4]			
	Blueberry	Orange, FL[4]		Kumquat		Casaba melon			Jaboticaba*			
	Caimito	Raspberry*		Mandarin[4]		Cranberry						
	Cashew apple	Strawberry*		Olive		Grapefruit[4]						
	Cherry			Orange, CA, AZ[4]		Juan Canary melon						
	Coconut			Pepino		Lemon[4]						
	Currant			Persimmon		Lime[4]						
	Date			Pomegranate		Pineapple[2,10]						
	Gooseberry			Tamarind		Pummelo[4]						
	Grape[6,7,8]			Tangerine[4]								
Ethylene-producing fruits and melons	Apple[1,3,9]	Plum		Durian		Avocado, unripe			Atemoya			
	Apricot	Prune		Feijoa		Crenshaw melon			Banana			
	Avocado, ripe	Quince		Guava		Custard apple			Cherimoya			
	Cantaloupe			Honeydew melon		Passion fruit			Jackfruit			
	Cut fruits			Persian melon					Mamey sapote			
	Fig [1,7,8]								Mango			
	Kiwifruit								Mangosteen			
	Nectarine								Papaya			
	Peach								Plantain			
	Pear, Asian								Rambutan			
	Pear, European [1,9]								Sapote			
									Soursop*			

Notes:

* Less than 14-day shelf life at recommended temperature and normal atmosphere conditions.

† Produces moderate amounts of ethylene and should be treated as an ethylene-producing fruit.

1. Odors from apples and pears are absorbed by cabbage, carrots, celery, figs, onions, and potatoes.
2. Avocado odor is absorbed by pineapple.
3. Celery absorbs odor from onions, apples, and carrots.
4. Citrus absorbs odor from strongly scented fruits and vegetables.
5. Ginger odor is absorbed by eggplant.
6. Sulfur dioxide released from pads used with table grapes will damage other produce.
7. Green onion odor is absorbed by figs, grapes, mushrooms, rhubarb, and corn.
8. Leek odor is absorbed by figs and grapes.
9. Onion odor is absorbed by apples, celery, pears, and citrus.
10. Pepper odor is absorbed by beans, pineapples, and avocados.

chute, does not drop below the thermostat set point. Good loading practices and well-cooled product in a supply-air-controlled refrigeration system allow thermostats to be set below 1.7°C (35°F). This is especially true for products with high sugar contents that freeze at temperatures significantly below 0°C (32°F) and for products that can withstand several episodes of light freezing conditions (table 20.3).

Many newer refrigeration units offer microprocessor-based controllers that automatically monitor refrigeration system operation and alert the driver to malfunctions. These systems can also transmit the information to satellites that forward the information to a company operations center. The company can then monitor vehicle location and system performance and maintain close supervision of all loads en route. This compatibility should allow companies to set thermostat set points closer to optimal conditions with less concern for load freezing.

Refrigerated trailers are used to carry a wide variety of products. The return trip to the production area may be a load of furniture, carpet, chemicals, or even pesticides. The truck owner and the company that contracts for transport of perishable foods need to ensure that residues from previous loads cannot contaminate food products with materials that are not registered food grade materials. The guidelines for best use of refrigerated trailers are shown in fig. 20.4.

Even with these records, cargo is sometimes misdeclared. Consequently, a trailer should always be well cleaned before each load of perishables to avoid contamination by non-food grade products or foodborne pathogens. Never load a trailer that is visibly unclean or has an odor from a previous load.

Some perishables may be handled in trucks or other vehicles that are not temperature controlled. For example, products may be shipped directly to the consumer in the mail, and flowers are sometimes shipped to florists on bus services. The customer or receiver will get adequate quality only if the product had a good shelf life to begin with and the transport time is relatively short. Many products are packed in closed, insulated containers to protect them from temperature extremes, both freezing and high temperature damage are possible. Ice or gel ice products that have been well sealed in bags are sometimes added to packages to protect the products from high temperatures. Produce should be immediately placed in a temperature controlled environment after it is received.

In some rural areas refrigerated vehicles are simply not available and produce is transported in open trucks or carts. Produce must be handled very quickly because most products have very limited shelf life under these conditions. Heat gain can be minimized by shipping the product during the cool part of the day or at night and covering it to reduce heat gain from the sun. A fabric or plastic cover should be opaque and light colored to reflect solar radiation. But more importantly the cover should be supported above the product to allow a small amount of outside air to flow between the cover and the product. Ventilation removes the heat that builds up under the cover. Clean plant material can also be used as a cover.

Table 20.3. Susceptibility of selected fruits and vegetables to freezing injury

Injured by one light freezing	Will recover from one or two light freezing episodes	Can be lightly frozen several times without damage
Apricot	Apples	Beets without tops
Asparagus	Broccoli	Brussels sprouts
Avocado	Cabbage, new	Cabbage, mature and savoy
Banana	Carrots without tops	Dates
Beans, snap	Cauliflower	Kale
Berries, except cranberries	Celery	Kohlrabi
Cucumber	Cranberry	Parsnip
Eggplant	Grapefruit	Rutabaga
Lemons	Grapes	Salsify
Lettuce	Onion, dry	Turnip without tops
Limes	Oranges	
Okra	Parsley	
Peaches	Pears	
Peppers, sweet	Peas	
Plums	Radish without tops	
Potato	Spinach	
Squash, summer	Squash, winter	
Sweet potato		
Tomatoes		

Source: Adapted from Hardenberg et al. 1986.

MARINE CONTAINERS AND REFRIGERATED SHIPS

Marine containers (figs. 20.5 and 20.6) and refrigerated ships (fig. 20.7) are used to transport perishables over the ocean. Ships have longer transport times than their typical alternative of air freight; travel times are often 1 to 4 weeks. However, their cost is

much lower than air freight, and both can provide excellent temperature and environmental conditions for long-term transport. The guidelines for best use of marine containers are shown in fig. 20.4.

The important differences between using containers or refrigerated ships relate to their differences in cargo-carrying capacity. A container carries about 1,000 to 1,500 packages, and a refrigerated ship has a capacity of about 350,000 packages. Their large insulated cargo volume and built-in refrigeration allow refrigerated ships to charge less than container systems that have a large number of small, individually refrigerated units. However, containers can be transported directly to a refrigerated loading dock at the packing operation, maintaining a continuous cold chain. Refrigerated ships are loaded from normal, open wharves and allow product to be exposed to the elements (heat, freezing temperatures, or precipitation). This is especially a problem in ships that use a common refrigeration system for two compartment levels because the refrigeration system is not operated until both compartments are loaded.

The large volume of refrigerated ships causes unique marketing problems. When 350,000 packages arrive at a port at one time, the sellers and receivers must have good marketing plan or a glut of product may depress product prices. Generally, refrigerated ships are used to transport produce that is marketed in large volumes by large

Figure 20.4

Guidelines for best use of refrigerated trailers, marine containers, and ships.

A. General

1. Products should be packaged in containers that are (see chapter 10 on packages for more details)
   - strong enough to withstand high humidity and vibration in transport
   - not stacked beyond the edge of a pallet
   - unitized and secured on a pallet
   - allow vertical air flow in bottom-air delivery transport (mostly marine containers and refrigerated ships)
2. Product must be cooled to proper transit temperature before loading.
3. Do not mix products that have different requirements for temperature, humidity, or are incompatible because of ethylene or odor sensitivity. Ethylene-absorbing materials can reduce ethylene damage if ethylene producers must be mixed with ethylene sensitive products.
4. Equipment must be in good condition before loading. Check to ensure that
   - Air delivery chute is in place and has no tears (mostly on trailers).
   - Door seals are in good condition.
   - Walls and ceiling are in good repair.
   - Floor and floor drains are clean.
   - Inside smells clean.
5. Vehicle should be cool before loading. Turn off refrigeration when doors are open.
6. There should be evidence that the thermostat has been calibrated.
7. Palletized loads should be well stabilized with netting or banding straps.
8. Do not allow product to touch air delivery chute; do not load above upper limit line.
9. Do not block airflow under load with crushed ice or solid load dividers.
10. Do not load product that is sensitive to vibration damage over wheel axles unless they have air ride suspension.
11. Use load bars or rear air bag to prevent rear product from shifting.
12. Place temperature monitor if needed.

B. For Highway Trailers Only

1. Check RTF classification plate to ensure that trailer was originally designed to handle the temperature conditions of the load. A C65 rating is rarely adequate for fruits, vegetables, or flowers.
2. Trailers must have a front bulkhead. Two pallets placed against the front wall can serve as a temporary bulkhead.
3. Do not load product directly on the floor unless trailer has a special deep-channel floor.
4. Load away from walls using stabilizing blocks or small inexpensive air bags.

C. For Marine Containers and Ships Only

1. Completely cover floor and pallet openings to force air through the load.
2. Produce containers should have bottom and top panel venting to allow vertical airflow. Vents must not be blocked by interior packaging materials or deck board of pallet.
3. Set fresh air exchange vent to prescribed level.

Figure 20.5

Refrigerated marine container.

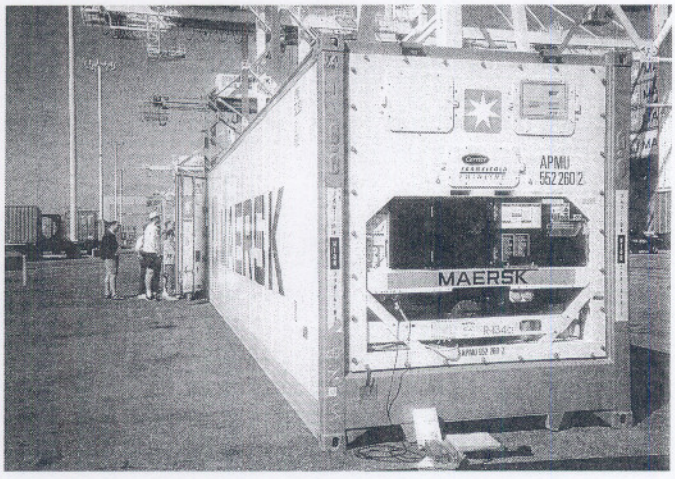


Figure 20.6

Refrigerated container ship.

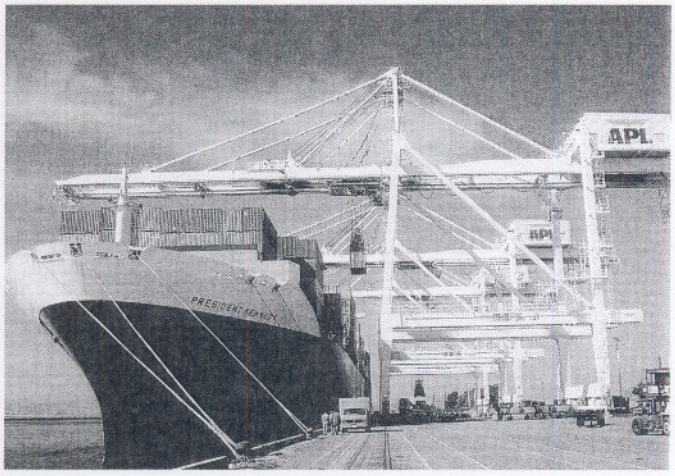
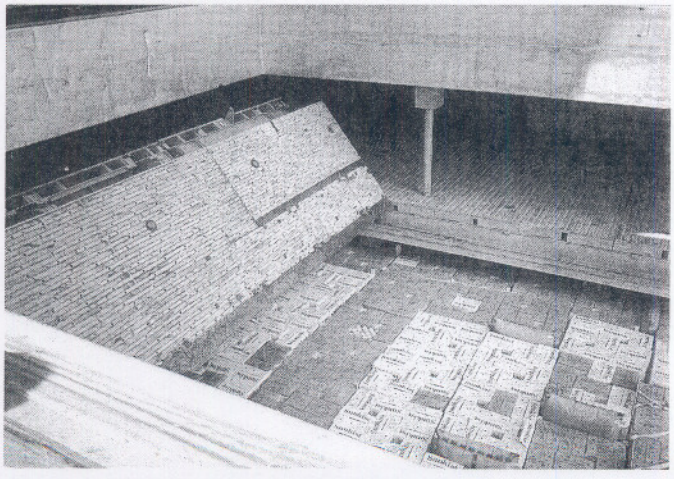


Figure 20.7

Filled hold of a refrigerated ship. Floor of topmost hold is being moved into place prior to filling.



companies. Transportation contracts may be arranged for a year at a time. Bananas, table grapes, apples, and citrus fruits are commonly transported in refrigerated ships.

The key differences between refrigerated marine transport systems and refrigerated highway vehicles are that they have a bottom-delivery airflow system (fig. 20.8), they can slowly cool product during transport, and they are more gas-tight, allowing them to be used for controlled atmosphere conditions in the stowage space.

Usual outside dimensions of refrigerated marine containers are a 12.2 m (40 ft) length, 2.4 m (8 ft) width, and 2.6 to 2.9 m (8.5 to 9.5 ft) height. Interior volume ranges from 56.6 to 65.1 m^3 (2,000 to 2300 ft^3). Refrigeration capacity ranges from 8.4 to 10.2 kW (2.4 to 2.9 tons). Marine containers are usually shipped over the road so the unit plus tractor and wheeled chassis must still not exceed highway weight limits.

Typical newer refrigerated ships have a stowage volume of 10,000 to 15,000 m^3, and some are as large as 22,000 m^3. The stowage volume is typically divided into four separate holds, each with three to five cargo compartments. The compartments have a standard height of 2.2 m (7.3 ft). Ships usually have their own cranes for loading. Cargo is loaded through hatch covers over the top compartments. Compartment floors can be opened to allow product to be loaded into lower compartments. Automatic temperature control systems can maintain supply-air temperature within ± 0.1°C (about 0.2°F) of the set point temperature. In steady operating conditions, load space temperature variation is less than 2°C (about 4°F).

Most of the recommendations for best use of refrigerated highway trailers apply to containers and ships (see fig. 20.4). However, best use of the bottom-air delivery system requires loading so that the refrigerated air is forced through and around the packages and not allowed to bypass around pallet units. Bottom-delivery systems can accomplish slow product cooling if air can flow vertically through packages. Citrus from California is usually cooled in marine transport. Seven-eighths cooling is achieved in about 100 hours. Products that depend on transport cooling should be packed in boxes that have at least 3% venting on top and bottom panels, and the vents should align even if boxes

Figure 20.8

Bottom-air delivery airflow system.

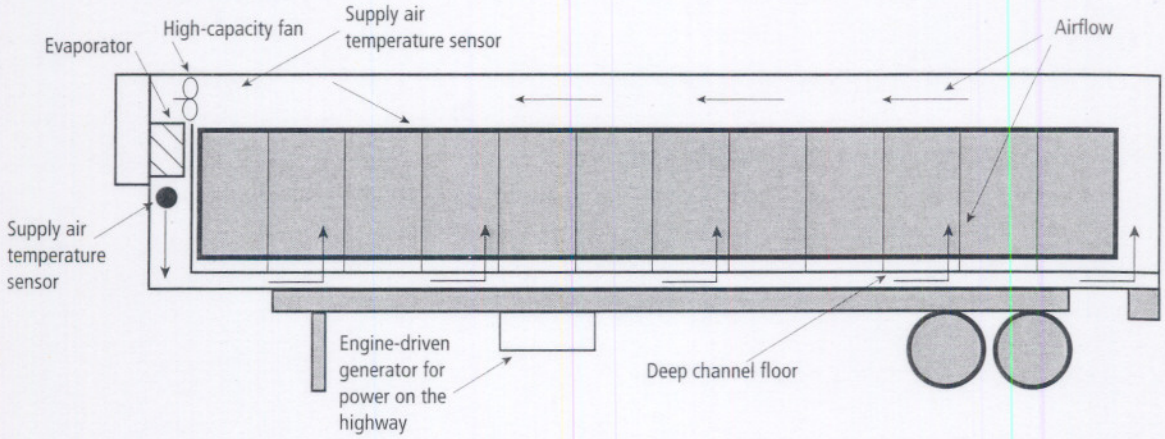
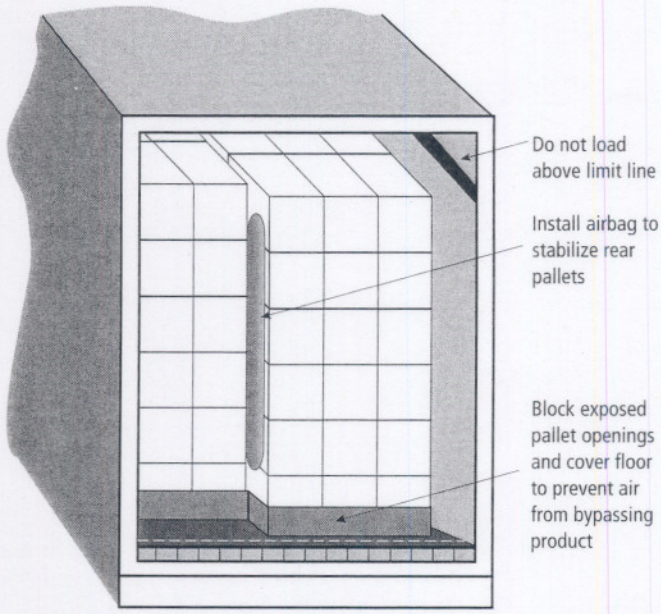


Figure 20.9

Proper loading of a marine container.



are cross-stacked. Interior packaging and pallet deck boards should not block airflow through panel vents.

The floor should be completely covered with product or solid material to force the refrigerated air around the packages and through the packages if they are vented for vertical airflow (fig. 20.9). If the product is palletized, open pallet edges should also be covered to block air from traveling horizontally through the pallet openings and escaping into an open vertical channel between pallet loads. Marine containers should not be center-loaded as is recommended for highway trailers. Many have corrugated walls that guarantee airflow between the walls and product.

If the floor and pallet openings are not completely covered, refrigerated air will bypass some of the load. Product with poor airflow around it will tend to arrive too warm, especially if it had not been thoroughly cooled prior to transport. Open floor in the front of a container allows the air to flow through this open area, and product in the rear of the container will tend to be warmer because little refrigerated air reached it.

Refrigerated containers and refrigerated ships usually have built-in temperature monitoring and automatic recording of refrigeration system functioning. These data are usually only available to the shipping company, unless a special arrangement has been made before the trip. Shippers should install their own temperature recording equipment for their records. Monitors are generally installed on top of rear pallets for convenience. In this location the monitor will be exposed to air temperature that is influenced by the temperature of the air produced by the refrigeration system and heat from the product. The temperature will also be influenced by loading that allows conditioned air to bypass the rear of the load.

Containers and refrigerated ships have controlled ventilation systems to prevent high CO_2 or low O_2 concentrations and reduce ethylene levels in the load volume. Container venting is usually set at a constant level at loading (see Thompson et al. 2000 for vent settings). Refrigerated ships often have instrumentation to measure gas concentrations and vary ventilation as needed.

Controlled atmosphere transport is commercially available on some refrigerated ships. This service is becoming available in containers with new generation units specially built with onboard atmospheric modification equipment. Third-party contractors can add modified atmosphere transport service to most refrigerated containers.

Internationally marketed fruit may need to be fumigated to exclude insect pests. Refrigerated ships can slowly warm product to methyl bromide fumigation temperature just before arrival, speeding handling at the port-side fumigation facility. Containers and refrigerated ships can also be used to meet quarantine requirements by holding product at low temperature. For example, USDA regulations allow control of Mediterranean fruit fly with fruit pulp temperatures of 1.1°C (34°F) for 12 days or 2.2°C (36°F) for 16 days.

RAIL CARS

Rail cars are used primarily for long-haul shipments within North America. Transportation times range from 6 to 10 days. They are mostly used to transport potatoes, citrus fruits, onions, carrots, and other less-perishable commodities. Rail shipments are often a single commodity. The cars have a stowage volume of more than 113 m^3 (4,000 ft^3) and can carry more than 45 metric tons (100,000 lb) of product.

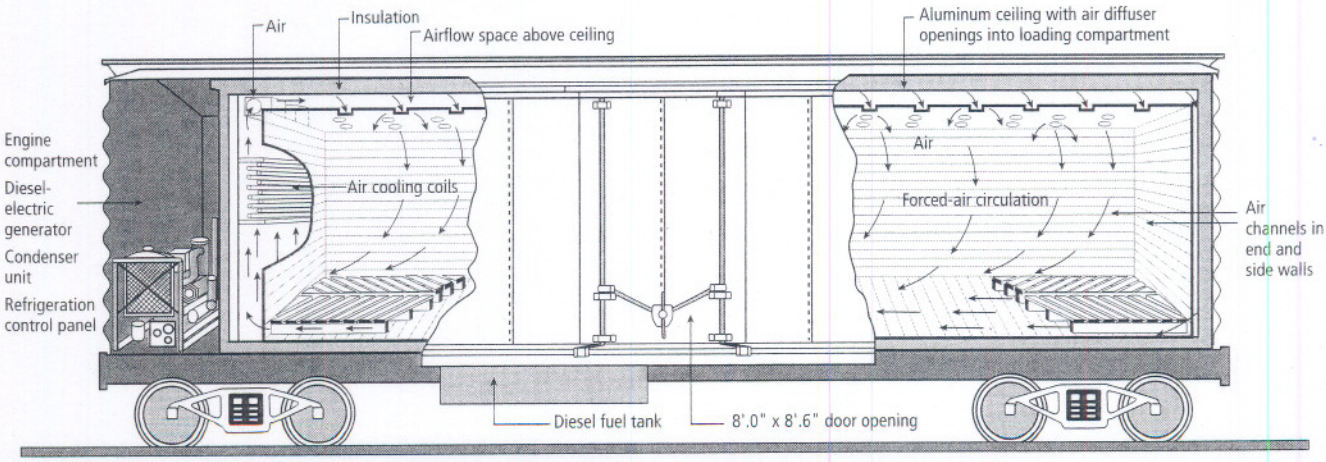
The cars have their own permanently installed engine-driven generator and electric-motor-powered refrigeration system. The system incorporates a return-air temperature control system. Conditioned air is supplied to a plenum in the ceiling of the car. Air flows past the product and down wall flues and then returns underneath the load to the refrigeration unit (fig. 20.10). The units have adequate airflow and refrigeration capacity to produce slow cooling of the product if it is not packed too tightly. The cars are very airtight when built and can be used for modified atmosphere transportation. Unintended atmospheric modification can occur if drain vents are clogged or water in them freezes in the winter.

Loading guidelines and package specifications for rail cars are generally specified by the railroad company or railroad organizations. Check with the transportation supplier for details. Very tight loads can restrict airflow and prevent air from traveling past the product. This may cause the thermostat sensor to detect warm air conditions and supply very cold air to the top of the load, causing some frozen product on the top of the load and warm product beneath. If crushed ice is applied uniformly to the top surface of the load, it blocks airflow and can prevent warm product below from being exposed to cooling conditions. If ice is used it should be applied to allow an open center area along the length of the car to permit airflow.

Several North American railroad companies offer trainload service for highway trailers that are designed to be fitted with railroad wheels. The trailers look much like conventional highway trailers, but are

Figure 20.10

Refrigerated rail car.



strengthened (adding about 500 kg [1,100 lb] to the vehicle tare weight) and can have special railroad wheels and couplers attached to them. They use regular over-the-road refrigeration equipment and often have air ride suspension. The vehicles can be placed on rails without the cranes or lifts needed for trailer-on-flatcar or container operations.

AIR

Air shipment is expensive and provides poor temperature control compared with refrigerated land and sea transport methods, but it often provides shorter transit times than competing methods. It is used mainly to transport highly perishable and valuable commodities to distant domestic and export markets. It is often used for early-season cherries, cut flowers, strawberries, and some tropical fruits. Products are transported in small aluminum containers that are shaped to fit inside the freight area of passenger planes or on net-covered pallets for transport in freight planes.

Most air transport containers are not refrigerated and provide minimal air circulation. Air temperature in cargo areas of planes is often set to provide safe conditions for live animals and is too warm for most perishables. At high altitudes air humidity in planes is extremely low, sometimes less than 10%, and can cause product dehydration if product is not packaged correctly or placed in a fairly airtight box. A few containers are available with CO_2 refrigerant. A battery-powered, thermostatically controlled fan moves air from the container past the refrigerant as needed to control temperature.

Improved temperature conditions can be obtained by wrapping the product to prevent warm air flowing past boxes (table 20.4). The wraps are sometimes made of reflecting materials to reduce radiant heat input when product is held on open docks or runways. Wraps should be removed if product warms to near room temperature because wraps may hold in respiration heat and cause product to heat above room temperature. Product is sometimes packed with enclosed ice, dry ice, or eutectic compounds to provide some refrigeration effect during transport. Use of dry ice must be reported to the airline because of the danger of CO_2 poising to animals or passengers. Water ice must be well enclosed to prevent water leakage and may require enough absorbent material in the box to contain an accidental leak.

Atmospheric pressure drops in flight to about 60% of sea level air pressure. Bagged product should be vented to allow pressure equalization. Bags for modified atmosphere packaging should be strong enough to withstand the low atmospheric pressure in air transport.

Travel time in the air is often in the range of 8 to 16 hours, but staging at departure and destination airports can add significantly to the total transport time. Staging areas of airlines are usually not refrigerated, and product can warm quickly, especially in hot, humid tropical climates, or it can freeze in winter conditions. Freight forwarding companies are often hired to arrange transport, handle the product at airports, and ensure best possible temperature conditions.

Table 20.4. Effect of pallet wraps on temperature rise of strawberries during air transport from San Francisco to several eastern U.S. cities

Pallet cover over open-top, tray-packed berries	Average arrival temperature
Corrugated fiberboard sheet on top of pallet	19.4°C (67°F)
Corrugated fiberboard on top and sides of pallet	12.2°C (54°F)
4 mil polyethylene film and corrugated fiberboard on top sides and under bottom boxes	8.9°C (48°F)

Source: Adapted from Harvey et al. 1966.

Note: Strawberries were originally cooled to 2.7°C (37°F); average transit time was 18 hr; average ambient temperature in the planes was about 15°C (60°F) and at airports ranged from 17°C (63°F) to 24°C (76°F).

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