For large trucks and trailers, another system uses a secondary refrigerant or brine circulated by means of the pressure generated by the sublimation of the solid CO_2. The dry ice is placed in pressure tanks located under the vehicle. Flow of the secondary refrigerant in the cooling coils on the ceiling is controlled by a thermostat located in the refrigerated space while the temperature of the brine is varied by means of a mixing valve. In this way the differential between coils and air temperature may be kept low when carrying fresh produce which requires a high humidity. For frozen foods the brine temperature may be lowered as required. The ability of the system to operate without any outside power source is an advantage for trailers. Johnson *et al* have reported on test results of such a system.[36]

Another type of dry ice system uses methylene chloride as a circulating secondary refrigerant which flows by gravity through plates or coils in the vehicle.[11]

Liquid Nitrogen or Liquid Carbon Dioxide Spray

In this relatively new adaptation of an old technique, liquid refrigerant is introduced directly into the cargo space through distributing lines and nozzles.[13,19,21,37] So far, liquid nitrogen or carbon dioxide are the principal refrigerants being used in this fashion. Refrigerant introduction can be controlled manually by hand valves or automatically by thermostat-operated solenoid valves. For road operation the refrigerant is carried in storage vessels preferably located in the refrigerated space. To eliminate the need for high pressure nitrogen tanks, the storage vessels can be insulated and equipped with relief valves set for about 15 psig and vented into the cargo space. Liquid carbon dioxide must be stored at pressures in excess of 60.4 psig, and at temperatures below 87.8 F. For precooling cargo after loading some terminals use liquid refrigerant sprays fed from dock-mounted storage tanks. In this operation the distributing tube can be introduced through a partially-open door. Caution must be taken to prevent refrigerant being released when any personnel are in the cargo space because of possible harm by suffocation, freezing or toxicity. Liquid carbon dioxide systems must be designed to prevent nozzle blockage by *snow* formation. Dougherty discussed some tests of retail trucks using liquid nitrogen.[37] Liquid nitrogen, with a boiling point of −320 F, costs from 2 to 8 cents per pound and has a net refrigerating effect, including superheating the vapor to 0 F, of about 160 Btu per pound. Liquid carbon dioxide, with a *boiling* point of −109 F, costs from 4 to 5 cents per pound and has a net refrigerating effect of about 120 Btu per pound including superheating the vapor to 0 F. Use of liquid nitrogen or carbon dioxide sprayed into the cargo space is being considered as auxiliary refrigeration to restore delivery truck temperatures after door openings.

Eutectic Plates for Holdover, with Station Charging Only

Most retail service low temperature trucks use some type of holdover plate arrangement. A holdover plate consists of a coil for the primary refrigerant mounted inside a thin tank filled with a eutectic solution with a freezing temperature sufficiently low to meet the required conditions. Sawyer described installation of eutectic plates in trucks.[33]

These holdover or eutectic plates come in many sizes, many forms, several thicknesses, and have numerous eutectic temperatures. Dimensions vary from 18 to 36 in. wide, from 40 to 120 in. long and from 1 to 3 in. thick. The refrigerating capacity and weight for a given size plate varies with the thickness. For example, a 30 × 66 in. plate of 2⅝ in. thickness has a refrigerating capacity of about 17,000 Btu (at −8 to −9 F eutectic temperature) and weighs about 300 lb, while the same size plate of 1½ in. thickness has a refrigerating capacity of about 9000 Btu and weighs about 225 lb. Standard eutectic plates operating at temperatures of −59, −29, −14, −12, −9, −8, −6, +18, 23 and 26 F are available.

Several of these plates are mounted on the walls, ceiling, or both, or are used as shelves or compartment dividers in the vehicle to provide the required refrigerating capacity while the vehicle is away from the garage or station where the plates are chilled. When the truck is garaged, flexible connections from the stationary refrigerating plant are attached to connecting devices provided on the truck. A *charging island* where several trucks can be connected at one time using hoses and self-valving fittings to attach the hoses can be used for fleet operation.[1,5] Any refrigerant can be used, the most common being Refrigerant 717 or, more recently, Refrigerants 12 and 22. Expansion valves may be mounted on the truck or on the garage wall, and various types of automatic-closure quick-connecting devices are available for attaching the flexible lines. In some plants using a chilled brine circuit, the plates are designed for circulation of the brine through the plates, rather than using the direct expansion of the primary refrigerant.

To provide proper cooling capacity, the plates must be mounted so that air can move freely on both sides, usually 1½ to 2 in. from walls with top edges 6 to 8 in. from the ceiling. On ceilings, plates should be sloped at least 1 in. per ft across the shortest dimension and should be at least 2 in. below the ceiling at the higher edge. Hangers must be securely fastened to walls, preferably by fastenings incorporated in the studs. Fastenings must not penetrate through to the outside wall surface. A drip trough may be desirable under each plate, although many vehicles are defrosted by scraping the frost without warming up the plates. If necessary to protect plates from damage, guard rails should be placed at least one inch away from plates.

Manufacturers' recommendations for methods of piping should be followed. Short connections are to be avoided between plates because vibration may cause breaks in pipe or tubing. Obviously, piping materials must be selected with regard for the type of refrigerant or brine. The weight of eutectic plates must be given careful consideration in planning total vehicle weight.

Eutectic Plates for Holdover with Vehicle-Mounted Condensing Unit

This system is becoming increasingly popular. Many trucks used for ice cream and frozen food service are equipped with condensing units having both an auxiliary drive for operation when the vehicle is in use, and an electric motor drive for standby. Some vehicles have only the electric motor drive, and must be inoperative for a sufficient period to refreeze the plates between runs.[29] The comparative length of time for the run and for refreezing is a factor in determining the size of condensing unit required. Installation of the plates is essentially the same as for systems which are charged by stationary plants.

Trucks equipped with a condensing unit which can be operated when the vehicle is in service, can use plate eutectic capacity adequate for normal operation and the unit can be operated for extra capacity during extended load periods. Electric motor drive units which use house current are dead weight during truck operation, but make it possible to garage the vehicle for refreezing anywhere that proper electric power is available.

Light duty holdover plates are used in some trucks which have condensing units driven by the truck engine to provide a continuous source of refrigeration during periods when the truck is not operating, such as during delivery stops, etc. In this application the condensing unit capacity must be greater than the instantaneous demand of the vehicle. Fig. 4 shows the installation of a truck-mounted condensing unit driven by a flexible shaft which is belt-driven from the truck engine crankshaft. Holdover plates provide continuous refrigeration even though the unit is idle when the truck engine is off. An electric clutch (magnetic) affords control of temperature. An electric motor can be provided for standby operation. (See section Mechanical Refrigeration Equipment.)

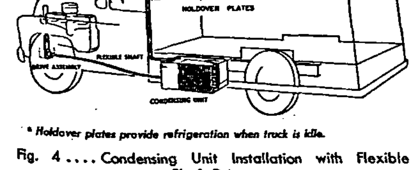
Mechanical Refrigeration, Independent Engine Driven

Many styles of independent engine driven mechanical refrigerating units are available and constitute the most popular application for both trucks and trailers. Descriptions and tests are discussed in References 1 to 12, 18, 25, 27, and 28.

The one piece plug-type design is a self-contained unit which mounts in an opening provided in the front wall of the vehicle. The condensing section is on the outside, and the evaporator section is on the inside, the two sections being separated by an insulated plug which is attached to the vehicle wall and which supports the various parts of the refrigerating unit. For trailers some of the plug units are tall and slender enough to mount between the tractor and trailer, others are short and deep and extend over the tractor roof.

Self-contained, independent engine-driven plug-type units of the type used in trailers primarily, depending on capacity, weigh from 800 to 1500 lb. Refrigerating capacity will range from 20,000 to 35,000 Btu per hr at a trailer temperature of 35 F in an ambient temperature of 100 F and will range from 6000 to 18,000 Btu per hr at a trailer temperature of 0 F in an ambient temperature of 100 F. Similar, but smaller self-contained plug-type units are available, ranging in weight from 400 lb to about 800 lb, again depending on capacity, for use in trucks.

Some units use two compressors, belt-driven, others one compressor either belt or direct driven by the auxiliary engine. These auxiliary engines may operate on gasoline from the truck tank, from a separate gasoline or diesel fuel supply on trailers, or on liquefied petroleum gases. Many are equipped with an electric motor in addition to the engine, for standby



* *Holdover plates provide refrigeration when truck is idle.*

Fig. 4 . . . . Condensing Unit Installation with Flexible Shaft Drive*

operation, and most units can be used for heating and can be defrosted by the hot gas method. Most units are thermostatically controlled, starting and stopping as refrigeration is needed. Condenser and evaporator fans are driven by the unit engine and tight fitting dampers close off the evaporator air flow to permit defrosting without unduly warming the vehicle interior. Most units defrost automatically. The one-piece construction facilitates replacement with another unit in the event of breakdown, or removal for maintenance.

Two-piece units are widely used for both trucks and trailers. One style uses an engine-driven generator mounted under the trailer to provide electric power to operate one or two independent refrigerating systems contained in a plug-type unit mounted in the front wall. The plug-type unit consists of a self-contained, 230 volt, 3-phase 60 cycle, hermetic compressor system, and the housing under the trailer contains an engine driven alternator. The compressor can be operated from house current during standby.

Another style uses an evaporator section, usually with electric motor-driven fans, mounted in the nose of the vehicle, and an engine driven condensing unit installed under the body. In this case, permanent piping is run between the condensing unit and evaporator, and a generator on the engine provides electric power to operate the evaporator fan. Some units are designed to cycle on thermostatic control, others operate continuously, but change speed of the engine in response to the need for refrigeration within the body. Some units are designed for automatic defrosting, others are defrosted by manual operation of hot gas valving, or electric heaters. Vehicles operating above 32 F defrost on the off cycle in the same manner as stationary units.

Mechanical Refrigeration, with Power Take-Off from Vehicle Engine or Transmission

For all practical cases, this type of refrigerating system is limited to trucks, although an axle-driven unit has been devised for trailers. Several types of power take-off means are available.[3,4,23] One manufacturer has an alternator, belt-driven from the engine crankshaft, which produces a regulated alternating current voltage which is rectified to drive direct current motors for the compressor and fans in the body. This is described by Tomkinson.[29] Temperature control is accomplished by cycling the compressor. Obviously refrigeration is produced only when the truck engine is in operation; full refrigerating capacity is claimed for all engine speeds above 500 rpm.

One manufacturer uses an all-electric self-contained hermetic unit to provide refrigeration for medium temperature truck bodies. A specially regulated alternator produces an alternating current power supply of variable voltage and frequency at essentially constant current for engine speed from idle operation to 4000 rpm. The alternator is mounted on the truck engine and belt driven from the engine crankshaft pulley. Standby operation is provided by electrical connection to regularly available alternating current house power. A two-speed centrifugally-operated gear shift is available to provide more suitable generator speed, if truck engine speed range is too wide.

Power take-off systems of the mechanical type sometimes have the condenser mounted in front of the truck radiator and flexible tubing is used to connect to the unit in the cargo space.

Some systems use an engine mounted compressor which is belt driven from the crankshaft pulley.

Various devices to guard against over speeding of the com-