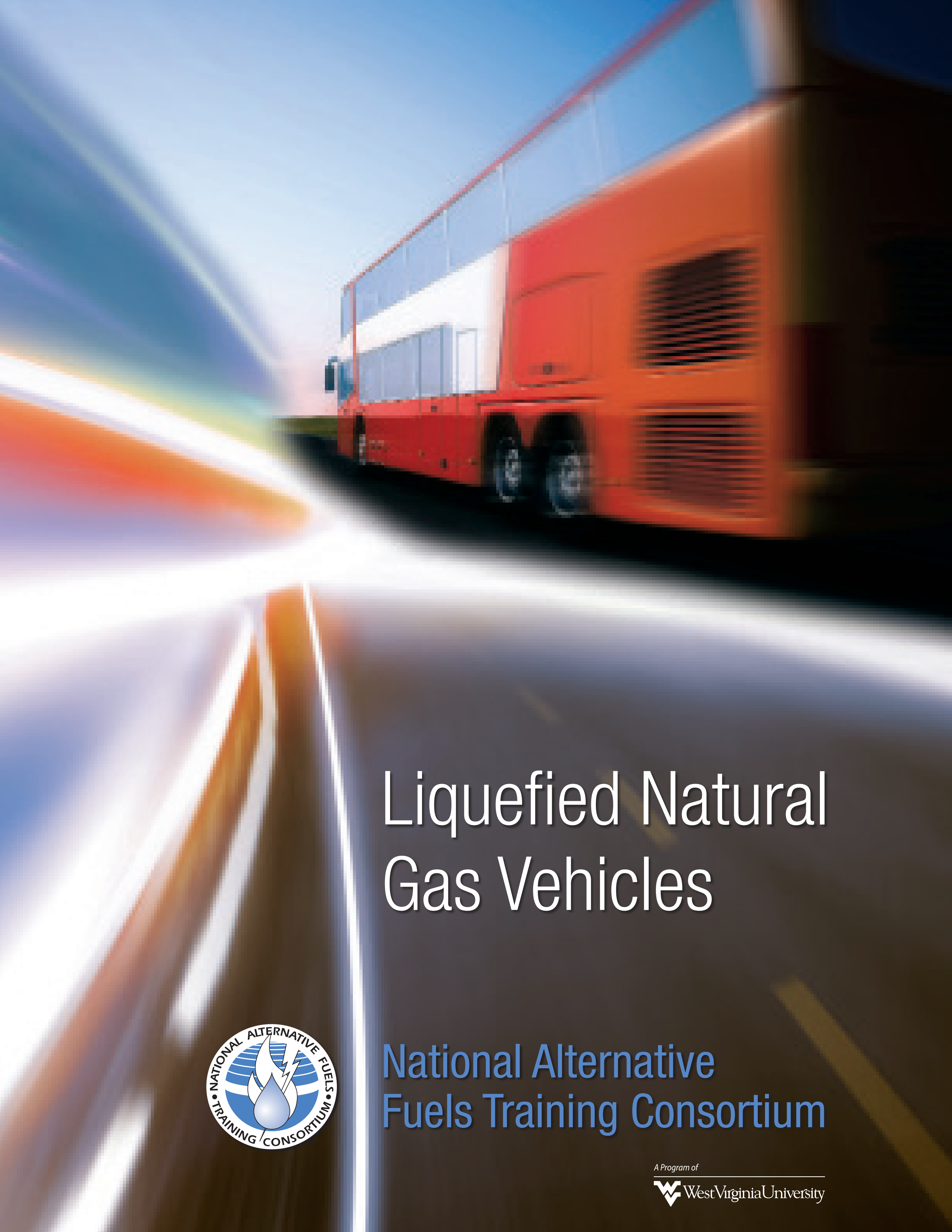

Liquefied Natural Gas Vehicles

National Alternative Fuels Training Consortium

A Program of
West Virginia University

Here is Why Pressure, Temperature, and Density Matter

Table 6-3 illustrates how the effective energy (the power to move the vehicle as fast and as far as it needs to go) in a given tank of fuel can change significantly as the temperature (and pressure) of the fuel rises.

These figures represent the effects on a NexGen Fueling HLNG-109 Heavy-Duty LNG Fuel Tank. The tank is 22 inches (56 centimeters) in diameter and 96 inches (244 centimeters) long; it has a gross water volume of 109 U.S. gallons (413 liters) and a maximum net volume of 98 gallons (371 liters) of LNG . Remember that maximum fill leaves 10% of the tank “empty” for methane vapor, so we have to subtract 11 gallons (42 liters) from the 109-gallon (413-liter) water volume.

Volume	Pressure	Temperature	Density
98 gallons (370.9 liters)	18 psig (1.2 bar)	–240°F (–151°C)	3.4 pounds per gallon
89.2 gallons (337.7 liters)	100 psig (6.9 bar)	–200°F (–129°C)	3.1 pounds per gallon
80.3 gallons (303.9 liters)	230 psig (15.8 bar)	–170°F (–112°C)	2.8 pounds per gallon

Table 6-3: Relationships that affect the energy density of LNG.

Table 6-3 also illustrates an important concept: a fuel gauge showing only the number of gallons in the LNG tank would miss two important facts:

1) When the tank is “full” it does not necessarily always contain the same number of gallons.
2) As the temperature of the fuel rises, its density decreases, which means that a gallon will not take the vehicle as far.

QUESTION: Why does the number of net gallons go down as the pressure rises?

Notes.

Filling, Venting, and Defueling LNG Tanks

The terms “hot” and “cold” are used for LNG fuel and tanks.

A **hot tank** can occur because of any of the following:

- The tank is new from the manufacturer.
- The tank has been out of service (empty).
- The tank has been allowed to sit containing only a small quantity of fuel. (In such a case, it typically takes at least four days for the tank to get hot.)
- The temperature and pressure of the LNG fuel that was delivered into the tank were above normal. One possible explanation for this is that the fuel was stored too long at the fueling facility, so that it warmed up and was delivered to the tank at too high a pressure.
- The tank was exposed to high-ambient or elevated temperatures for a considerable length of time (4 to 30 days). For example, the vehicle was parked in direct intense sunlight.
- The tank is mounted improperly: either too close to the engine with little or no insulation separating them, or too close to the exhaust system without an insulating barrier.

A **cold tank** can occur because of any of the following:

- The tank has been **overfilled** with cold LNG; the liquid level is more than 90% with less than 10% ullage space.
- The tank has been fueled with **very cold** LNG—lower than –240°F (–151°C) at a very low pressure (less than 20 psig or 1.4 bar), and the fuel is at a pressure too low to operate the system.
- The tank has been recently purged with very cold liquid nitrogen vapor, and the inner vessel has not warmed sufficiently to permit boiling of the cold/low pressure LNG being fueled into the tank.

Cooling a Hot Tank

The LNG tank is hotter than acceptable for operation. This can occur during normal operation for any of the reasons listed above:

The preferred and safest way to cool down a hot tank is as follows:

1) SLOWLY introduce a small amount of cold fuel into the tank—approximately 5 gallons (19 liters). This MUST be done gradually to insure that the tank is not **thermally shocked**, which can damage the integrity of the tank. Introduce 5 to 15 gallons (19 to 57 liters) of LNG (depending on the tank capacity) into the hot tank.
2) Wait for a few minutes and allow the rising vapor pressure from the expanding fuel to vent to a SAFE place.
3) Repeat this procedure until the tank is cooled. Using this method, even large tanks (70-150 gallons or 265-568 liters) can be cooled down and put into service in about thirty minutes.

Note: The Environmental Protection Agency (EPA) considers methane (a “greenhouse gas”) a serious environmental hazard, and it is expected to be regulated soon. Most fueling facilities have a **vapor recovery system** to prevent direct venting to atmosphere. If such a system is not available, venting small quantities of methane is acceptable, as long as it is done safely.

If the tank is relatively full and has built a high “false head” pressure from any of the procedures above, SLOWLY vent off vapor to a SAFE place in order to cool the LNG and return the tank to a normal pressure/temperature range (see Note above).

Figure 6-16 shows a “hot” tank being filled. Note the frost on the valves and hoses.

Notes.

Figure 6-16: "Hot" LNG tank being filled—note that the tank head is frosted on the fill hose and valve, as well as the vent valve and hose.

Warming a Cold Tank

The LNG tank is colder than acceptable for operation. This can occur during normal operation for any of the reasons listed above.

The preferred and safest way to warm a very cold LNG tank is as follows:

1) Vent 30-40% of the fuel from the vehicle tank into a **defueling tank** (see Figure 6-17). If a defueling tank is not available, there may be a **defueling circuit** available at the fueling station and a defueling connection may be fitted to the vehicle tank, as shown in Figure 6-18.
2) Allow the fuel to warm in the defueling vessel (see Figure 6-19). The amount of time required by this process depends on factors such as ambient temperature and the initial temperature of the fuel. This process could take from several days <u>up to several weeks</u>.
3) Refuel the vehicle tank with the warmed fuel.
   Caution: The vehicle should be parked in a safe indoor area or outdoors, so that vapor can be safely vented without creating a fire hazard.

Another effective, <u>but not recommended</u>, solution is as follows:

1) Carefully introduce a small quantity (not more than 100 standard cubic feet) of CNG, regulated to no higher than 85 psig or 5.9 bar (just enough to overcome tank pressure) into the tank. This will create a false-head pressure, which can be used to operate the vehicle.
2) When acceptable operating pressure is reached and is relatively steady, run the engine to draw from the tank. This process should withdraw vapor from the tank, drop the pressure and encourage boiling. This may require a few recharges with CNG until fuel pressure/temperature are high enough to operate the vehicle.

Notes.

Figure 6-17: Defueling tank, shown next to a trash hauler.

Figure 6-18: Defueling tank hose connected to vehicle tank port.

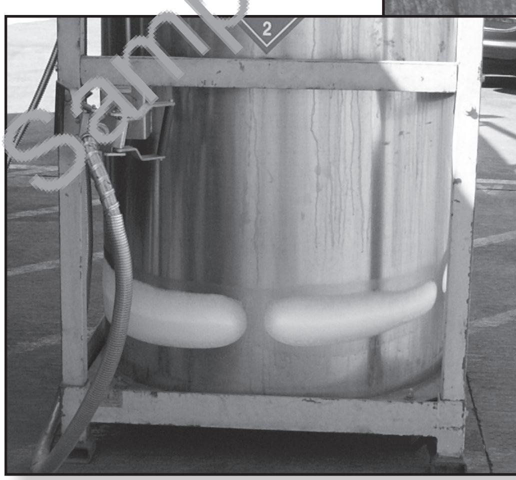

Figure 6-19: Defueling tank warming circuit frosted on outer tank.

Defueling a Tank

Before servicing the system, the technician must become familiar with the fill circuit components and how they fit into the system.

WARNINGS
Working on a system under pressure can injure or kill you! Make sure that **no pressure is present in the system** before loosening any fittings, filter housings, or gauges. Turn off all tanks and run the engine to lower fuel pressure. Then check all high-pressure gauges. Fittings that could be pressurized if the tank contains fuel include the following: liquid and vent valves. backflow check valve. excess-flow valve. economizer. PRD(s).
NEVER use external heat sources to defrost connections—you might ignite leaking gas!
Do not let LNG come in contact with your skin. Always wear the proper protective clothing and equipment!

Fuel leaks must be repaired as soon as possible in order to avoid fire or injury. Small leaks have been temporarily minimized with a wet (water-soaked) shop rag wrapped around the fitting.

If they leak, the fill and vent receptacles might be rebuilt—always follow the manufacturer's recommendations.

The most effective way to defuel a tank is to use a **defueling tank**—as already shown in Figure 6–17. The procedure involves the following steps:

1) Lower the pressure of the defueling tank until it is 20 to 30 psig (1.4 to 2.1 bar) lower than the vehicle tank pressure.
2) Connect the defueling tank to the vapor vent on the vehicle tank—refer to Figure 6-18.
3) The high-pressure fuel in the vehicle tank will flow out to the low-pressure defueling tank.
4) As pressure rises in the defueling tank, vent the defueling tank to atmosphere (or to a methane-gas collection system).
5) Continue to vent off the remaining fuel in the vehicle tank until it is complete empty.
6) Service the tank as necessary.
7) Meanwhile, open the pressure-building valve on the defueling tank to circulate fuel through the warming circuit—see Figure 6-19.
8) Once the defueling tank reaches adequate pressure (150-200 psig or 10.3-13.8 bar), fuel can be reloaded into the repaired vehicle tank (or to a new one).

Caution: During these procedures the interconnective plumbing, such as tank valves and other related components, can become very cold (lower than –100°F or –73°C). Be careful to avoid any contact between unprotected skin and these components. Proper safety equipment must be worn while performing these operations. Leak testing is also a must. When using CNG, you must follow all safety procedures for dealing with pressurized gas. If you are not familiar with these precautions, **do not use this procedure**!

Notes.

Filling Procedures

LNG tank valves are labeled **LIQUID** and **VENT**.

The liquid (fill) valve is always a manually-operated valve; the vent valve may be either a manual valve or a pneumatically-controlled valve. The tank in **Figures 6-16** shows a manual liquid valve and a pneumatic vent valve—they are labeled Liquid Shutoff Valve and Vapor Shutoff Valve.

Every LNG system must have a manual liquid shutoff valve to meet the requirements of NFPA 57. This valve stops the flow of fuel to the engine or isolates one tank from other tanks on the vehicle. Manually-operated tank valves used on LNG tanks have a spring-loaded rotary stem. This is designed to automatically compensate for thermal shrinkage and wear. It can be repaired after the tank is completely drained of fuel and the valve is allowed to warm. Refer to manufacturer's recommended procedures.

Figure 6–20 illustrates remote fill and vent connections. On the right-hand side of the picture you can see the fill port and hose (top) and the vent port and hose (bottom). On the left, you can see three pressure gauge connections and three pneumatic control valve hoses mounted vertically—one for each tank.

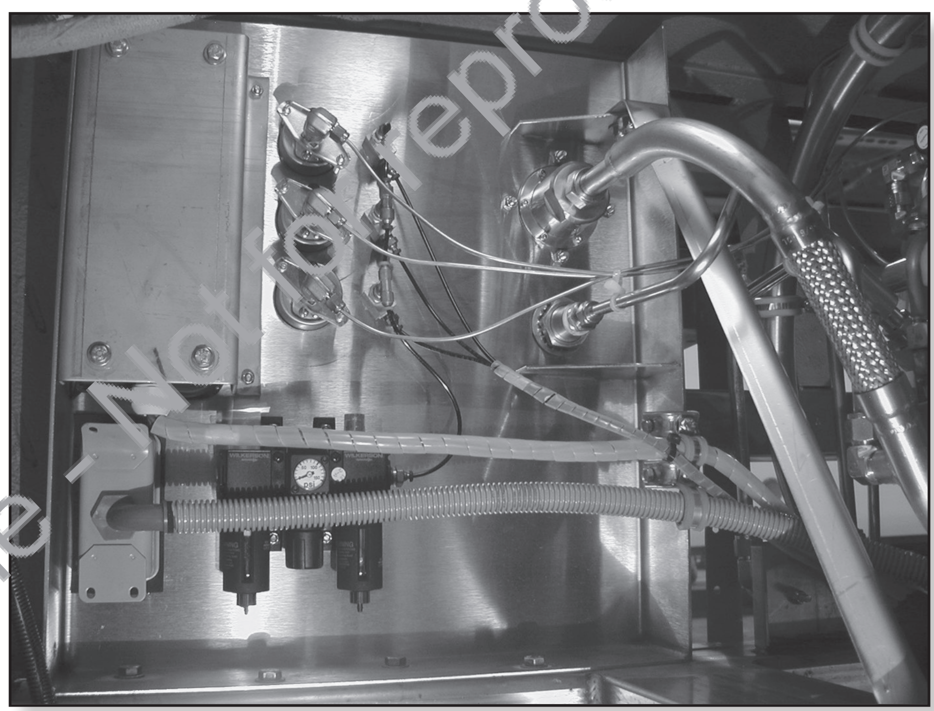

Figure 6-20: Back side of a fueling panel, showing connections from the panel to the tank.

Tank fueling is done by using either the normal filling method (single hose) or vent filling method (two hoses). Single-hose filling is recommended by tank manufacturers, but it is not always possible.

Normal or Pump Filling with a Single Hose

Pump pressure will generally overcome pressure in the warm tank. This occurs because the cold fuel entering the tank flashes into vapor and pressure rises. However, **<u>extreme caution</u> should be used when introducing cold fuel into a warm tank**.

Pump filling is also called **single-hose filling** (see Figure 6-21) and is done only if there is a pump in the fuel station. The liquid fuel entering the tank is colder than the fuel already in the vehicle tank. The colder fuel collapses the vapor head in the vehicle tank (temperature drops—pressure drops), reducing tank pressure and filling the tank.

When the fuel level reaches the top of the fill tube inside the tank, pressure rises rapidly. The fuel station dispenser senses the pressure rise and shuts off the fuel flow automatically.

Pump pressure can overcome pressure in the warm tank. However, if the tank is very warm, the cold fuel being introduced will flash into vapor, causing pressure to rise dramatically. This is why it is important to use caution when introducing cold fuel into a warm tank.

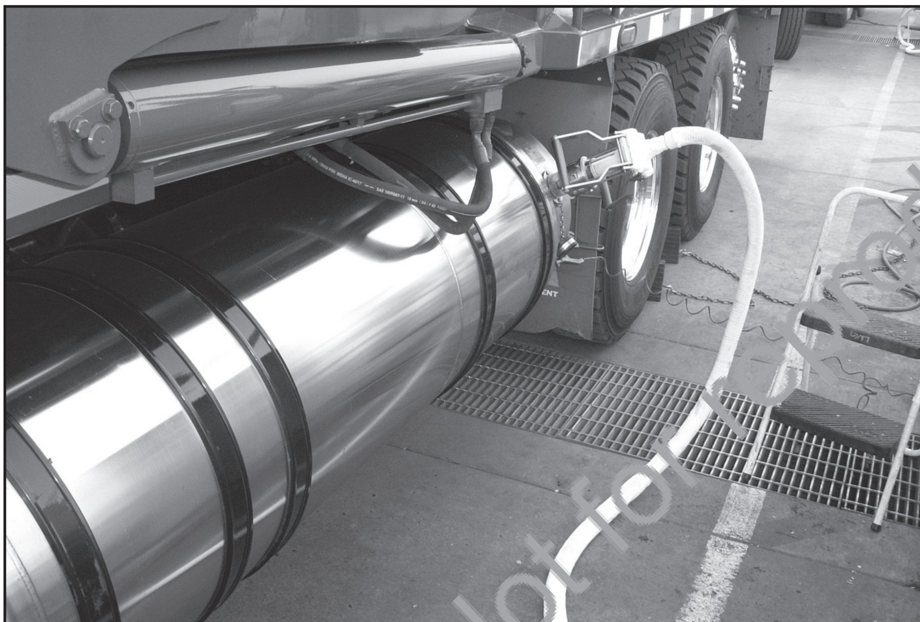

Figure 6-21: Normal or single-hose filling.

Venting Filling and Warm-Tank Filling

Some LNG filling systems use gravity to feed fuel into the vehicle's tank(s)—such systems do not include a pump to overcome pressure in the vehicle tank. If the pressure from the gravity-feed system is not adequate to completely fill the vehicle, it is necessary to vent the vehicle tank while filling. This process is similar to the "cooling a hot tank" process that has already been discussed.

Tanks are typically vented using a hose attached to the LNG dispensing station which vents to the atmosphere. Figure 6-22 shows a close-up of the pneumatic venting solenoid and related vent plumbing on a three-tank assembly. Remember that the vent circuit may be either manually- or pneumatically-operated. One branch off the vent circuit goes to the other two tanks. The other branch contains a check valve. This valve connects to the tube that vents away all three tanks to the port on the fuel panel, which is rated at 10 gallons per minute (gpm). The check valve in the vent-away pipe protects individual tanks from backflowing into the other tanks.

Figure 6-23 shows the fueling panel for a NexGen three-tank assembly. In the case shown, warm tanks are being fueled using a gravity-feed system. Cold fuel is being dispensed into the fill valve, while fuel vapor is being taken away from the tanks through the vent port. The bus is being fueled for the first time at a station that does not have a pump.

In Figure 6–23, the pneumatic control buttons are being held open (covered) by three pieces of hose and locked open by a metal rod. This picture was taken at the manufacturing facility.