Chapter 2

The Nature of LPG Products, Their Storage, Measurement, and Delivery

Objectives

Upon completion of this chapter, you should be able to:

1. Describe the basic physical properties of LPG products.

2. Describe the conditions under which these products must be stored to maintain their liquid state.

3. Describe the basic elements of an LPG liquid-measuring and delivery system.

4. Identify major types of delivery devices and installations commonly found in the marketplace.

Introduction

The devices used for measurement of LPG products in their liquid state are quite similar in design and operation to a number of other liquid-measuring devices such as vehicle-tank meters and loading-rack meters. Except for the special materials used for some internal components and the differential pressure valve (used to maintain system pressure at levels required to preserve the liquid state of the product) that LPG liquid-measuring systems employ, they are virtually identical to the equipment used for tank truck and bulk measurement installations for liquid petroleum products, fertilizers, chemicals, etc.

What makes LPG measuring equipment different from other liquid-measuring devices and necessitates different specifications and test procedures for examining them in the field are features of the delivery systems on which they are installed. The design of the delivery system is in turn directly related to the physical and, to a lesser extent, the chemical properties of the liquid that is dispensed and the operating conditions under which it is dispensed.

This chapter provides an introduction to the systems that are used for commercial measurement of liquid LPG. (Devices used for measuring LPG products by weight or by gaseous volume are not covered in this manual.) We will first look at the distinctive properties of these products, and then describe the special requirements for design and operation that arise from these properties. We will also summarize the major types of systems that are employed for deliveries in various applications.

Anhydrous Ammonia

Metering systems used for the measurement of anhydrous ammonia are very similar in design and operation to systems used for LPG products. In fact, when applying examination procedures, LPG and anhydrous ammonia liquid-measuring devices may be considered to be virtually identical.

Appendix C of this manual includes a discussion of the properties of anhydrous ammonia, as well as points of difference in the conduct of field examinations, especially regarding safety procedures. If your jurisdiction is involved in examining anhydrous ammonia liquid-measuring devices, your instructor will discuss this material with you.

LPG Properties And Characteristics

Liquefied petroleum gas (LPG) is defined as a petroleum product composed predominantly of any of the following hydrocarbons or mixtures thereof: propane, propylene, butanes (normal butane or isobutane), and butylenes. These substances are generally extracted from natural gas or produced as a byproduct of the refining of crude oil. Commercial propane and, to a lesser extent, butane are the principal LPG products that we will be concerned with. Commercial propane, however, is not a pure product but a mixture of LPG products, with the primary component being propane (commercial LPG is generally more than 90 percent propane). It may also contain up to 7 or 8 percent ethane, a neo-cryogenic hydrocarbon.

A relatively rare combination of physical properties accounts for the prominent place of LPG in the marketplace. The most important of these properties is that LPG products are gases at atmospheric temperatures and pressures, but they can be liquefied and maintained in their liquid state with relative ease.

For example, propane, the hydrocarbon that comprises about 90 percent of most commercial LPG, occupies approximately 270 times less space as a liquid than it does as a gas: about 270 cubic feet of propane gas are condensed into 1 cubic foot of propane liquid (at 60 °F). Butane has a slightly lower ratio, but as a liquid still occupies less than 0.5 percent of the volume it would occupy as a gas (again, at 60 °F).

The main value of LPG products results from the fact that they can be stored in their liquid state and used in their gaseous state. In their condensed, liquid state they can be stored and transported much more efficiently than they could be as gases. The advantage in reduced transportation and storage costs is sufficient to offset the cost of liquefying these products and also produce a profit. For this reason, and because of the value of the products themselves to consumers, production of LPG products has grown rapidly since they were first introduced in the marketplace more than half a century ago.

To use LPG in most commercial and industrial applications it must be reconverted to a gaseous state. This is easily accomplished simply by returning it to atmospheric temperature and pressure. When we say that gaseous LPG products are "easily liquefied," this must be understood in relative terms. To be liquefied, a substance must be maintained at a temperature below its boiling point. The boiling point of a substance is the temperature at which it will change from its liquid state to its gaseous state. To bring about the transformation from a liquid to a gaseous state, a certain amount of heat must be applied to the liquid at its boiling point. This is known as the latent heat of vaporization. Propane, the principal component of most LPG, has a boiling point of -44 °F at atmospheric pressure, which is approximately 14.7 pounds per square inch (psi). The boiling point of butane (also at atmospheric pressure) is much higher, +32 °F.

Even though such temperatures are attained under certain climatic conditions in certain parts of the country, it is obviously impracticable to transport and store the products as liquids only when and where these temperatures occur naturally. Furthermore, temperatures sufficiently low to maintain propane in its liquid state are not attainable using normal refrigeration methods. Consequently, LPG products are liquefied by refrigeration but maintained in the liquid state by pressurization.

The pressure that must be applied to maintain a contained product in its liquid state at a given temperature is unique to that product and is a function of temperature. That pressure is known as the vapor pressure of the liquid. Just as the boiling point of a substance, such as water, varies with its pressure, the vapor pressure of a contained LPG product varies with temperature.

Temperature and Vapor Pressure

A temperature of 60 °F is more or less in the middle of the range of temperatures normal for a temperate climate. The approximate vapor pressures for the two principal LPG products at 60 °F are:

Propane - 100 psig

Butane - 12 psig

For example, at a temperature of 60 °F a vapor pressure of 100 psig is needed to maintain LPG in its liquid state. If the temperature of the LPG is raised to 100 °F the amount of vapor pressure required to keep it in a liquid state would be 172 psig. Thus, it takes considerably higher vapor pressure to maintain propane in its liquid state at 100 °F than at 60 °F. At higher temperatures, higher vapor pressures will be needed to maintain the product in its liquid state. At 100 °F the vapor pressure of butane is approximately 38 psig, more than three times its vapor pressure at 60 °F, though considerably lower than the vapor pressure of propane at that temperature.

Temperatures required to liquefy these products are quite easily produced by refrigeration equipment, and containers can be fabricated that will securely hold several times the vapor pressure of propane within normal temperature ranges. As a result, LPG products are stored and transported in closed containers. LPG is metered from those containers at ambient temperatures, but at pressures higher than atmospheric pressure. It is obvious that one requirement of any system used to measure and deliver these products is, therefore, that it be a closed system so that the product can be held at a pressure sufficient to maintain its liquid state. Since the product is customarily stored by the purchaser as liquid until it is used, the storage vessel must also be closed and be connected to the delivery system when product is dispensed in such a way that they function as a closed system.

The properties described above also relate directly to requirements for measurement of liquid LPG products. Since they are normally metered and sold by liquid volume, it is especially important that the product be in its liquid state when it passes through the metering device. The reason for this is that, as mentioned above, a given weight of the product will occupy many times its volume in its gaseous state as in its liquid state. You may recall, for example, that gaseous propane occupies about 270 times the volume it would as a liquid. Since the buyer of the product is purchasing liquid product by volume, any gas in the form of vapor included in the volume measured will result in the customer paying for more product than has actually been received.

Temperature and Volume Changes

LPG products, either in their liquid or gaseous state, expand when heated and contract when cooled. Thus, even if it is maintained as a liquid, a given weight of propane, for example, will occupy more volume if it is warm than if it is cold. Again, since the purchaser and seller complete their commercial transaction based upon a measured volume of liquid product, the temperature at which it is sold can make a difference.

In fact, for LPG products the temperature can make a very great difference, since among their physical properties is a high rate of change in volume with change in temperature. For example, commercial liquid propane expands or contracts by about 1 percent of its volume for each change of temperature of 6 °F.

Because of this property, sales of LPG products are often (though not always) based upon the volume sold at a reference standard temperature of 60 °F. To avoid the necessity of heating or cooling the product to exactly this temperature, the quantity indicated by the measuring device is usually corrected for its deviation from this standard, either by an automatic device called, a temperature compensator, or by calculations based upon a volume correction table. In later chapters you will learn how such corrections are actually made.

Storage Vessel Headspace

There must be a certain amount of headspace above the level of liquid in the tank to allow for the expansion that will occur if the temperature of the tank and its surroundings increases, even by a small amount. In addition, as product is drained from the tank during normal operation, some liquid product will vaporize in response to the drop in pressure and will generally remain as vapor, filling the upper portion of the storage tank. We will see how the delivery system is designed to keep vapor out of the measuring elements in the next section.

Design of the Delivery System

Now that you are aware of the properties of LPG products that affect their storage and measurement as liquids, we can turn to the general characteristics of the design of the delivery system. Figure 2-1 represents, in greatly simplified detail, the design of any LPG delivery system. The system has four basic components: a storage tank, a pump unit, a metering unit, and the piping (including valves and other control elements) that connects these components and leads from the metering unit to the discharge nozzle. As you can imagine, the actual design is considerably more complex and includes a variety of accessory elements. We will look at these specific details in the next chapter and concentrate for the moment on the essential functional components of the system.

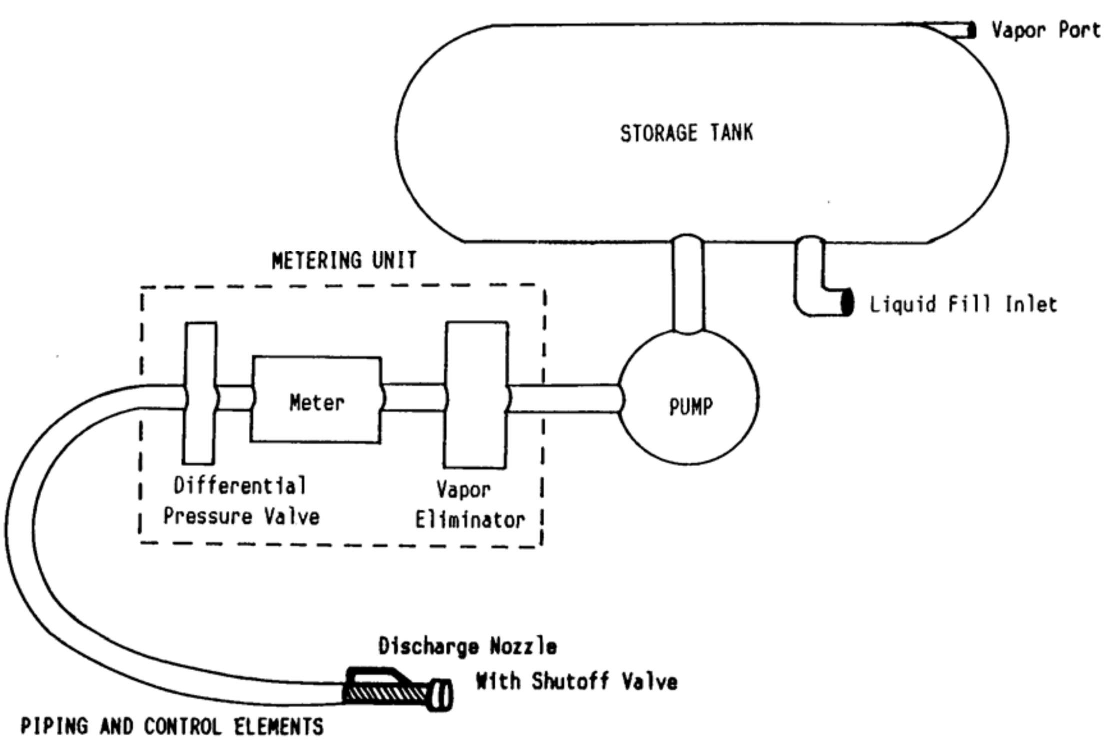

Figure 2-1. Basic components of an LPG delivery system.

As mentioned above, the entire system is closed and must permit no leakage of liquid or vapor. It must also be designed and constructed to withstand high pressure. Specifications regarding operating pressures that these systems must be capable of withstanding have been developed by the American Society of Mechanical Engineers (ASME: "Pressure Vessel Code," Section 8) and have been adopted as part of most State fire and safety codes. The system must also be equipped with pressure relief valves, which are designed to permit a controlled venting of product to the atmosphere when internal pressures exceed safe limits. The design and operation of these valves will be described in the next chapter.

Storage Tank

The storage tank is equipped with a liquid fill inlet for supplying the system with product, and the system has a discharge line with an outlet for delivery. In addition, a vapor port is provided; this permits the use of a pressure equalization line, which is sometimes necessary for efficient delivery under certain extreme conditions (as explained below) and for volumetric testing or calibration of the system (described in Chapter 4).

Pump

The pump provides the pressure needed to propel product through the delivery system and into the receiving tank. Its design and operating characteristics are determined by its application. If properly selected, its capacity, in terms of discharge rate and pressure, will meet the requirements of the systems to which it delivers product.

Metering Unit

Liquid product is measured as it passes through the metering unit. In addition to the measuring device itself, this component includes an indicating element, which is designed to indicate, or register, the quantity of liquid that has passed through the meter. The indicating element is driven directly by the measuring element, so that measurement and registration occur simultaneously. This allows the operator of the system, and the purchaser of the product, to monitor the amount of liquid that is being delivered continuously throughout the delivery. The design and operation of these measuring and indicating elements will be described in more detail in the next chapter.

Vapor Eliminator and Differential Pressure Valve

In addition to the measuring and indicating elements, the metering unit also includes two separate devices, a vapor eliminator and a differential pressure valve. The function of these devices is to prevent vapor from entering the meter and being measured along with liquid product.

The vapor eliminator separates any vapor that has been produced from the liquid flow before it reaches the meter and returns it to the vapor space of the storage tank; the differential pressure valve maintains the product in its liquid state as it passes through the meter. As liquid is drawn from the storage tank, pressure within the tank falls. When it has fallen below the vapor pressure of the product -- as will happen almost immediately -- some of the liquid will boil (that is, change from its liquid state to its vapor state). In doing so, it expands rapidly and rises from the liquid into the vapor space. This also has a cooling effect (because of the latent heat of vaporization, which must be absorbed from the product in order to bring about the transformation in state from liquid to gas). The resulting expansion in volume will restore the equilibrium condition that exists in the tank almost instantaneously. As a result, whenever liquid product is being delivered, some vapor is being produced in the storage tank at the same time.

This vapor is generally of no concern to accurate measurement of liquid product since it remains in the storage tank and does not enter the pump or metering unit. However, vapor can be produced in any part of the system where even a slight pressure differential occurs. A fall in pressure is likely to occur at any point where flow is restricted for any reason. This may occur at the pump, at valves, and at points where different sizes of piping are joined.

Vaporization may also occur if a temperature differential exists at any point. A temperature differential will occur if one portion of the piping is exposed to direct sunlight, heating product at that location. Liquid product is also heated by friction as it flows through the system, especially at points where it must flow against gravity, around bends, or through a restricted passage. Even though the vaporization that occurs at any one point in the system as a result of any particular factor may be very small, any accumulation of vapor may have a significant effect on measurement accuracy.

The design of the system must thus be such as to minimize vaporization due to these conditions. For example, piping should be no more extensive than necessary, as straight as possible, and should avoid upward pitches. This is especially important for the piping that leads from the storage tank to the inlet of the pump. It is also generally recommended that piping leading to the pump be one size larger than the discharge piping. The number of pipe connections and valves should be kept to a minimum, and the pump and meter should be carefully selected to match the operating conditions under which the system must perform, especially in terms of capacity and pressure.

As mentioned above, vaporization of product is also reduced by a differential pressure valve, which eliminates pressure differentials by restricting flow on the discharge side of the meter, thus maintaining a uniform pressure in the piping and metering element upstream that is at or above the vapor pressure of the product. This device is an important part of the system design.

However, it is not always possible to eliminate all sources of vapor production in the system and deliver product efficiently at the same time. As a result, the system must incorporate effective means of eliminating the vapor that is produced by collecting it and returning it to the storage tank vapor space, where its presence is innocuous. A device called a vapor eliminator performs this function. We will look more closely at the operation of both the vapor eliminator and differential pressure valve in Chapter 3.

In summary, the principal design requirements of the system as a whole are that it must:

- Contain product under pressures that are within its safe operating range, and be provided with means to effect a controlled venting of product when internal pressures exceed those limits.

- Be capable of delivering product efficiently (that is, at a rate of flow and discharge pressure that are appropriate for the receiving vessels to which product is delivered).

- It must reduce to a minimum the production of vapor within the system and must be equipped to eliminate small amounts of vapor that are produced.

Receiving Vessel

Before leaving this general overview, let us look briefly at the problem of moving liquid product within a closed system from the point of view of the receiving vessel. Figure 2-2 illustrates how the factors we have been discussing affect delivery.

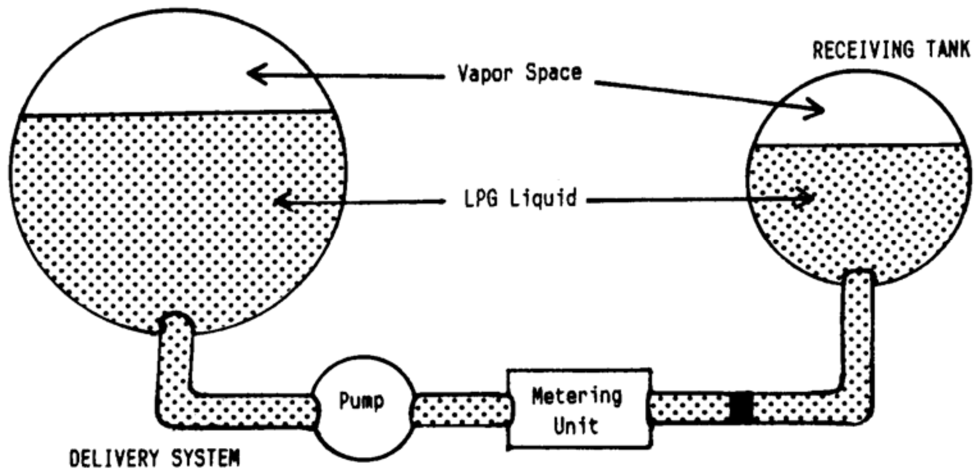

Figure 2-2. Delivery of product.

The receiving vessel, like the delivery system storage tank, will contain some vapor and some liquid at all times, although at the time of delivery its contents may be mostly vapor. The situation described above for the system storage tank works in reverse in the receiving tank during delivery of liquid product as product is pushed into the receiving tank.

As liquid enters the receiving container, propelled by pressure from the delivery system's pump, it displaces vapor. As the level of liquid rises, it acts like a slow-moving piston, compressing vapor in the space above it. This compression causes a rise in pressure and temperature. As the pressure rises, some of the vapor begins to condense and return to the liquid phase. Equilibrium is eventually, but not instantaneously, restored.

In older vapor return systems, this situation was remedied by connecting a vapor line between the vapor space of the receiving tank and the vapor space of the system storage tank. Excess pressure could thus be bled from the receiving tank, and equilibrium would be maintained in both tanks. This solution, however, meant that some amount of product belonging to the purchaser was being returned to the seller in the form of vapor.

A far better and more equitable solution involves an adaptation of the receiving tank. A pipe from the receiving tank inlet is extended into the vapor space. The outlet of the pipe is designed in such a way that incoming liquid product is sprayed upward toward the top of the tank. The droplets of cooler liquid spray falling through the vapor space promote condensation of the vapor, thus cooling the compressed vapor. This in turn lowers pressure and allows the system pump to deliver more efficiently. This method, called spray fill, may be accomplished in several ways, as shown in Figure 2-3.

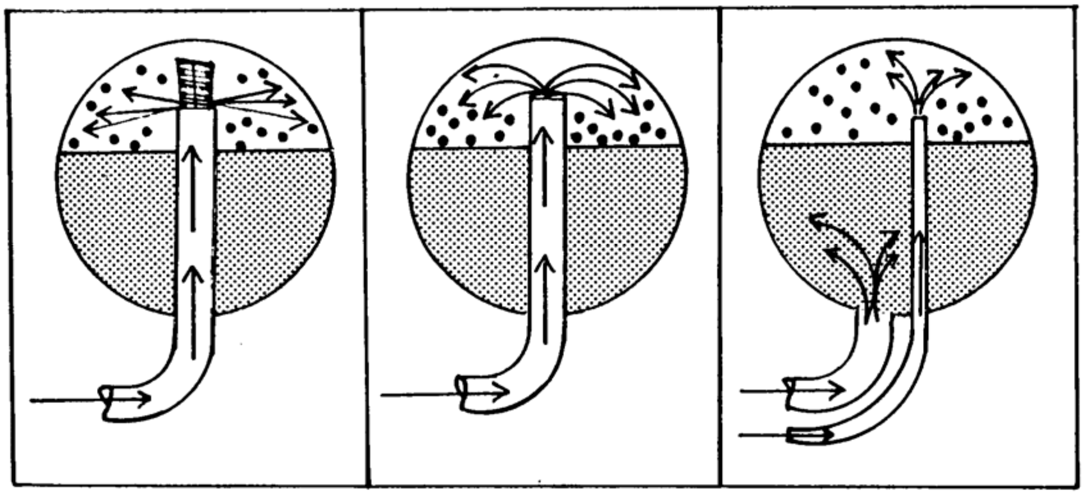

Figure 2-3. Spray-fill method of delivery.

This design of receiving tanks has now become virtually universal and thus has made vapor-return lines unnecessary, except under the most extreme climatic conditions. As a result, most States have prohibited the use of vapor-return lines in commercial deliveries, except under very specific and limited circumstances. This prohibition is also included among the requirements of NIST Handbook 44 and will be discussed again in Chapters 6 and 7.

The effects of temperature expansion of the liquid product must also be considered in determining how much product should be delivered to a receiving tank. In general, the colder the liquid that is delivered, the greater the amount of head space that should be allowed for expansion. The reason for this is that if the product delivered is colder than the tank and the surrounding air temperature, it will expand as it warms. This process will be gradual, and it may take a number of hours before the product has warmed -- and expanded -- fully. For this reason, sufficient vapor space must be preserved in the top of the receiving container to permit expansion of product. Provisions of National Fire Protection Association (NFPA) 58 ("Storage and Handling of Liquefied Petroleum Gases") and Department of Transportation (DOT) regulations ("Hazardous Materials Regulations," 49 CFR 170-179) for filling cylinders, storage tanks, tank trucks, and tank cars allow adequate vapor space for liquid expansion as the result of a change in atmospheric temperature.

Types of Delivery Systems

The basic design features described above apply to all types of systems used for measurement and delivery of LPG. These are not the only design criteria, however. The design of the system must also reflect its use in a specific delivery application in the marketplace.

Wholesale deliveries are generally made from bulk distribution centers or terminals to tank trucks. Because of the large capacity of truck tanks, delivery can be made safely and efficiently at relatively high flow rates, usually in the range of 100 gallons per minute (gpm), and sometimes considerably higher.

Tank trucks make deliveries either to retail stations or directly to customers. Because receiving tanks are considerably smaller, these systems generally operate at lower discharge rates, depending upon the type of service. Trucks delivering to large holding tanks at a retail installation generally are equipped for maximum discharge rates of about 50-60 gpm. Retail deliveries to smaller tanks kept by farmers and homeowners are usually still lower, about 30 gpm.

In many parts of the country, retail sales of LPG products are also made from service stations. Customers may either fill small truck- or trailer-mounted tanks at these facilities or, in the case of propane products especially, refillable cylinders may be used.

In some parts of the country, LPG is used extensively as a motor fuel. In recent years, filling stations for LPG-fueled vehicles have been constructed that appear quite similar to gasoline filling stations, with similar dispensers and controls familiar to motorists. However, most LPG motor-fuel refilling facilities are nothing more than a tank, pump, meter, and hose. Because receiving tanks and fill pipes on motor vehicles are relatively small, these systems typically deliver product at comparatively low flow rates, usually about 10 gpm. The tank, pump, meter, and piping of an LPG delivery system are selected and designed as a unit, depending upon the purpose of the system.

Summary

The appropriate design of metering and delivery systems used for LPG is determined by the physical properties of the product, especially its response to changes in temperature and pressure during delivery. To assure accurate measurement, the design of the system must incorporate means to minimize vaporization and to eliminate any vapor produced before it enters the metering element. Receiving tanks must also be designed to facilitate both efficient delivery and accurate measurement. The design of the metering system also depends upon its use and especially upon the desired maximum discharge rate. Metering systems for LPG are commonly installed in fixed locations or on tank trucks and are used in both wholesale and retail service.

Terms to Know:

boiling point. The temperature at which a substance will change from its liquid state to its gaseous state. The boiling point of a product is a function of pressure.

latent heat of vaporization. The amount of heat that must be applied to a liquid at its boiling point to bring about the transformation from a liquid to a gaseous state.

vapor pressure. The pressure that must be applied to maintain a contained product in its liquid state at a given temperature. The vapor pressure of a product is unique to that product and is a function of temperature.