How Temperature and Pressure-Drops Affect Pump Transfer Rate

By Walter Smith

The transfer rate from a pump handling LP-gas is dependent on more than several variables. Beginning in 1945, for the first time, these began to be quantified, and by the end of the 1950s, the industry was able to predict a pump transfer rate and the factors that affect it. My company has been involved in testing, defining, and quantifying such variables for a very long time. Factors such as vapor entrainment, cavitation, NPSHA (Net Positive Suction Head Available to the pump), temperature, and differential pressure are some, as well as others.

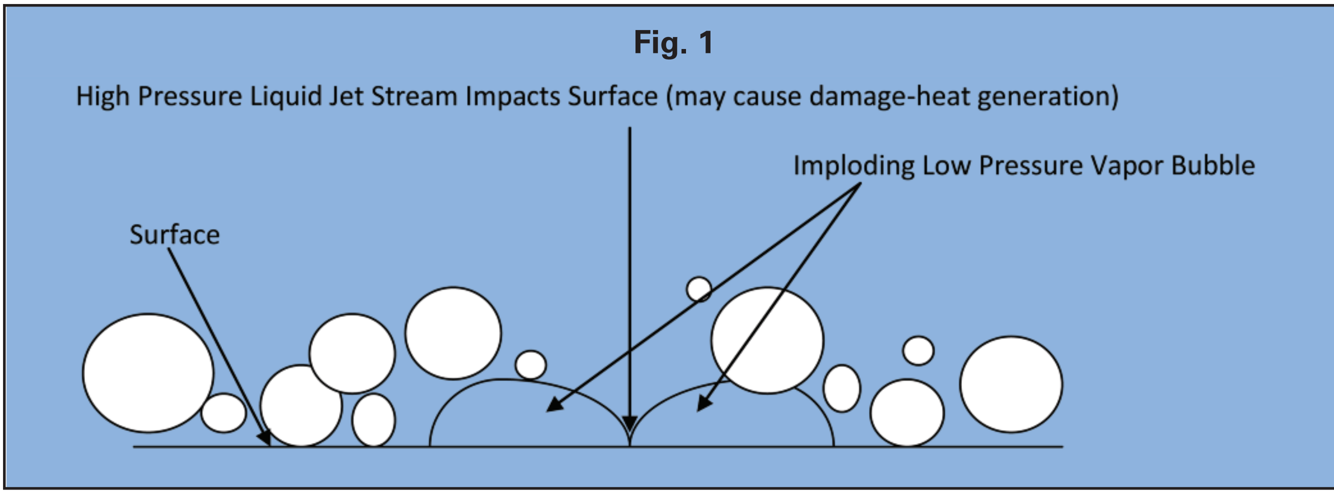
Vapor Entrainment

Propane is generally stored at or near its boiling point. Simply put, if the pressure in a closed system drops, vapor will be formed instantly. Since vapor displaces liquid, positive displacement pumps that are designed to transfer liquid, not vapor, may not be fed with the amount of liquid the pump is designed for. It is quite obvious that a pump designed to transfer 60 gpm cannot do so if only 50 gpm is made available on the inlet side of the pump. Vapor formation on the inlet side of the pump will not necessarily cause the pump to cavitate. Vapor formation will, however, starve the pump. Chronic pump starvation will wear pump components and slow down the delivery rate.

What can cause vapor formation on the pump inlet? Aside from heat transfer from a high-temperature environment and rapid drop of the liquid level in the supply tank (discussed under the Differential Pressure section), this is caused by a pressure reduction created by what is commonly referred to as a restriction. The restriction increases the velocity of the liquid and creates a pressure drop (reduction). Note there already is a pressure drop on the inlet side of the pump due to the friction of the inside diameter of the pipe, fittings, directional changes of the liquid created by elbows, tees, strainers, valves, the pump itself, and any other appurtenance in the installation. If the pump is properly installed, there is enough vertical distance between the pump and the liquid level in the tank to "overcome" this normal pressure

Table 1. PERCENTAGE OF REDUCTION IN LP-GAS PUMP CAPACITY WHEN THERE IS INSUFFICIENT STATIC HEAD PRESSURE

Liquid and Temperature	Difference Between the Height the Tank should be Mounted and the Height it is Mounted, in Feet											
	1	2	3	4	5	6	7	8	9	10	11	12
Propane 100° F.	0.7	1.4	2.0	2.7	3.3	4.0	4.6	5.2	5.8	6.5	7.1	7.6
Propane 70° F.	1.4	2.8	4.1	5.4	6.6	7.9	9.0	10.2	11.4	12.4	13.5	14.6
Propane 40° F.	3.0	5.9	8.9	11.1	13.6	15.8	18.0	20.1	22.0	23.9	25.7	27.3
Propane 10° F.	6.9	12.9	17.9	22.0	27.1	30.8	34.2	37.3	40.2	43.5	45.1	47.2
Propane -20° F.	16.3	28.0	36.8	43.7	49.3	53.9	57.6	60.8	63.7	66.1	68.1	70.0
Butane 100° F.	7.4	13.7	19.3	24.1	28.5	32.3	35.7	38.9	41.7	44.3	46.7	48.8
Butane 70° F.	15.3	26.5	35.1	41.8	47.3	51.9	55.8	59.0	61.8	64.2	66.3	68.3
Butane 40° F.	30.9	48.3	58.4	65.3	70.2	73.8	76.7	79.1	80.8	82.6	83.8	84.9



drop. This is a dynamic situation because the liquid level in the tank is not static, but is constantly dropping, so the vertical distance becomes less and less (NPSHA). This is one reason why it is a best practice to use the vertical distance from the bottom of the tank (instead of the liquid level) to the pump inlet when determining how far under the tank the pump should be mounted. If this is followed, it makes no difference what the liquid level is in the tank to overcome the pressure drop on the pump inlet from a wide variety of sources. Three- and four-inch flanged inlet type truck pumps designed to be mounted directly to the internal valve are very close to the bottom of the tank, so the NPSHA is much less than in a typical bulk plant situation. However, there is no pressure drop associated with pipe, tees, elbows, and other appurtenances normally associated with a typical bulk plant installation. In this case, the pressure drop is solely associated with that of the internal valve, internal valve strainer, and the pump itself, excluding any pressure drop in the supply tank. At 30°F, a 1-psi reduction in pressure below the supply tank vapor pressure will cause a 14% vapor increase. A 2-psi reduction in pressure will cause a 25.5% vapor increase, and a 3-psi reduction will cause a 33% vapor increase. At 70°F, the vapor increase is roughly one-half these values.

Table 1 gives figures for the percent reduction in pump capacity when there is not adequate vertical distance from the pump inlet to the liquid level in the tank. Note that as the temperature drops, the percent reduction increases.

Cavitation

Much research has been conducted regarding cavitation and its effects. It is a field of fluid mechanics that has garnered much attention over the years (it was actually "discovered" in the late 19th century). There are many definitions of cavitation. Cavitation should be defined including a cause and effect in the case of LP-gas transfer. One reason is because cavitation starts with vapor formation, but it is the dynamic interaction of liquid and vapor that causes cavitation to occur. In other words, vapor formation on the inlet side of the pump may not necessarily cavitate the pump or cause damage.

A simple definition of cavitation is "the sudden formation *and collapse* of low-pressure bubbles in liquid." Does this tell the whole story? No, it does not. In the case of LP-gas transfer, sufficient vapor bubbles must begin to collect on a surface. These vapor bubbles are formed when the pressure falls below the "normal" vapor pressure. If the liquid level in the tank feeding the pump drops to a level that is inadequate to overcome the resistance to flow of the strainer, internal valve, pipe, fittings, valves, tees, elbows, etc., on the pump inlet side (flange-mount truck pumps include the internal valve strainer, internal valve, and resistance to flow of the pump itself), vapor will be formed. In addition, at high temperatures, if only 25% of the volume of the supply tank is unloaded at one time, a pressure drop of approximately 8.4 psi (100°F) will occur in the supply tank and more vapor is formed. This will affect the performance of the pump, and in cases where the bubbles are pronounced and plentiful, cavitation may occur. When this manifests itself, the bubbles will implode (*Fig. 1*), creating very high shock waves as well as localized heat. This is what causes noise and vibration in a pump. Studies have shown that very small amounts of debris held by surface tension in the bubble wall actually weaken the bubble. The shock wave is therefore not necessarily perpendicular to the surface where the bubbles congregate. This explains why cavitation damage can migrate from where the implosion occurs.

Our experience through the years suggests that the size of the bubbles in the liquid the pump is transferring, plays an important role in pump performance and is one reason why the performance of a pump transferring butane is compromised, especially at lower temperatures. We theorize one reason for this is because the vapor pressure is lower than that for propane and this allows the vapor bubbles to be larger (it must also be noted that at lower temperatures, the size of propane vapor bubbles will also be larger). Should cavitation manifest itself during a transfer, greater shock waves are produced due to the larger bubble size and have a more pronounced effect on pump performance. Should cavitation not occur, more liquid is displaced by the larger bubble size in any event, and pump performance is compromised. Even at 60°F, one pound of propane vapor takes up a volume of 1.01 cubic feet, or about 7.5 gallons. Compare this with butane vapor, at the same tem-

Table 2. PRESSURE REDUCTION IN TANKS BEING UNLOADED WITHOUT THE USE OF EQUALIZING CONNECTIONS, FOR PROPANE

Temperature of Propane in Tank at Start (Degrees F.)	Percentage Volume of Tank Unloaded in One Operation			
	25%	50%	75%	100%
100	8.4 psi	18.7 psi	34.5 psi	76.9 psi
70	4.3 psi	10.0 psi	18.3 psi	39.9 psi
40	2.1 psi	4.2 psi	9.3 psi	21.2 psi

perature, that has a volume of 3.40 cubic feet, or over 25 gallons. Thus, pump starvation issues involving vapor entrainment and possible cavitation initiation will be more than three times as evident when transferring butane.

Those that study the fluid dynamics of cavitation assert that the degree of cavitation and the shock wave produced depend in large part on the tensile strength of the wall of the bubble. One could then assert that the bubble wall is weaker at low temperatures because the bubble is larger (use the analogy of blowing up a balloon—the rubber skin becomes thinner and thinner). The propensity for bubble implosion and hence true cavitation then becomes ripe at lower temperatures. That being the case, the constituent make-up of the LP-gas in itself, along with the quality of LP-gas, also plays a role; however, I am not aware this has yet been quantified. This would help to explain serious pumping issues that may occur at low temperature extremes.

Differential Pressure

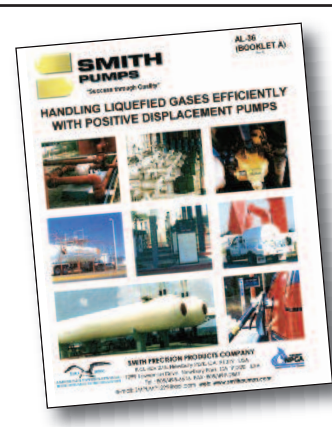
For vapor bubbles to form and cavitation to initiate on a surface, an area of low pressure must exist, surrounded by higher pressure. With liquefied gases like propane, conditions for a "Perfect Storm" almost always exist. Under good conditions, there is always slippage taking place in a pump. This is another reason why the delivery rate goes down as the differential pressure rises. In general, a small amount of the high-pressure liquid on the discharge side of the pump slips back to the inlet side of the pump, within the pump. This occurs at high velocity; however, the vapor bubbles that form as a result are very small. With a pump in good working condition installed in an adequate manner and used within average ambient temperatures, this will not create a cavitation condition. But temperature extremes may play a role in pump slippage, allowing for more vapor formation due to slippage that may initiate a cavitation condition. Worn pump parts, especially those that produce pressure, can also contribute to vapor formation and initiation of cavitation.

As liquid is drawn from the supply tank, the space formerly occupied by liquid must be filled with vapor. In systems not using a vapor return line, it must come from the liquid that remains in the supply tank. The liquid in the tank being unloaded boils continuously while the pump is in operation. The necessary vapor can be created in no other way. Since boiling requires heat, and little heat is applied from the outside, most of the heat has to come from the liquid remaining in the supply tank. As heat is taken away from the liquid, the temperature of the liquid becomes lower and lower. This lowering of temperature reduces the pressure in the tank being unloaded, which increases the differential pressure across the pump, and hence slows the delivery process.

The amount of pressure reduction created in this way during a transfer period depends on two factors: (1) the temperature of the LP-gas in the supply tank at the start and (2) the percentage of total LP-gas fuel capacity of the supply tank that is unloaded at any one time. Referring to *Table 2*, it is easy to see that the higher the temperature of LP-gas at start, the greater the pressure reduction. Also note that the greater the percentage of fuel unloaded in any one operation, the greater the pressure reduction. *Any* pressure reduction translates into an increase in vapor formation. An increase in vapor formation decreases the pump transfer rate.

The back pressure built up in tanks being filled also contributes to the differential pressure across the pump; however, it is quite low on a very cold day (as low as 1.6 psi with propane at –20°F). This is not true on a very hot day (as high as 31 psi with propane at 100°F). Back pressure has also been well-defined through the years. When added to the pressure drop of pipe, tees, elbows, valves, couplings, meter, hose, and any other appurtenance used on the pump discharge, the total pressure drop can be calculated and the pump differential pressure determined.

To summarize, the topics briefly discussed in this article are just three factors that can affect the delivery rate from a pump. The subject matter is complex, but we can come close to quantifying most of the variables involved. The ambient temperature is the driving force, and, at extremes, can diminish the transfer rate. I hope this article helps to explain why.



For more detailed information on pump transfer rates, a 32-page booklet is available from Smith Precision Products Co. Go to *http://smithpumps.com/literature/pdf/BOOKLET_A.pdf.*

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