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How Cold Weather Affects Tank Capacity

It's during severely cold weather that the LP-gas system faces it's most serious challenge. These are the times of freezing equipment, low tank pressure, and peak customer demand. The portion of the LP-gas installation put under particular stress by winter conditions is the tank and its vaporization rate. Understanding the factors affecting the capacity of an LP-gas system during cold weather therefore becomes vitally important.

The operation of an LP-gas system depends upon the vaporization of the compact liquid stored in the tank. Expanding in volume as much as 270 times, propane vaporizes into a gas which supplies pressure to move itself through the system before it is finally burned as a fuel. It is this central principle of vaporizing liquid fuel that is so adversely affected by winter temperatures.

The liquid in the container must use the temperature difference between its boiling point and the outside temperature in extracting enough available heat to permit vaporization. When gas is withdrawn from the tank, the pressure is lowered below that of equilibrium, lowering the liquid's boiling point. This action causes more vapor to boil off to restore the pressure. Cold weather results in a reduced tank vapor pressure simply because there is less heat energy In the atmosphere to boil off the liquid fuel into vapor.

Frost Halts System

A tank will meet load demands until gas is removed faster than boiling can replace it. When this occurs, the outside walls of the tank are chilled, inducing precipitation on the walls from the surrounding atmosphere. During the winter, moisture on the tank surface quickly transforms into frost up to the level of the liquid. As the layer of frost develops, it acts like an insulator on the tank, greatly restricting heat transfer from the surrounding air to the liquid. The system then fails because the vapor pressure falls below that needed for satisfactory regulator performance.

A simple formula governs the vaporization capacity of any given tank. It is as follows:

$$Q = U \times \%A \times (T_1 - T_2)$$

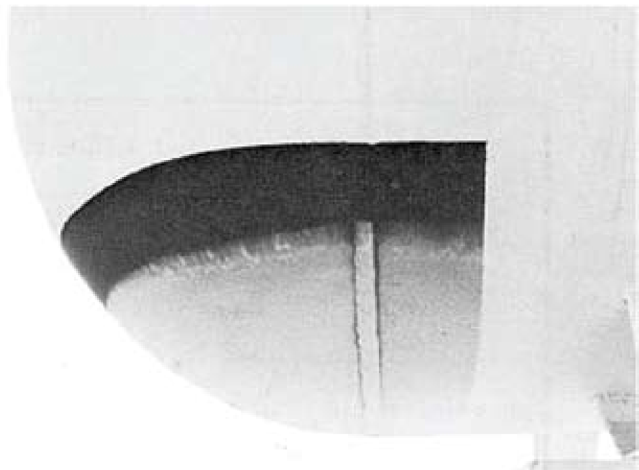

Figure 1. Layer of frost on underside of tank. The tank has been painted black in that area to make it easier to identify this condition.

Where:

- Q = Heat transferred from the atmosphere through the tank walls into the liquid (Btuh)
- U = 2, which is a coefficient accounting for the convective heat transfer from the air to the tank wall, the thermal conductivity through the wall,and the convection from the inner surface to the liquid (Btu/ft.^{2} hr. °F); 2 is an average number since wind and sunlight affect this factor
- %A = Area of the tank surface up to the level of liquid (ft.^{2}); this is the only portion of the tank transferring significant heat
- $(T_1 - T_2)$ = The difference in temperature between the air temperature, T_1, and the temperature of the liquid in the tank, T_2.

The most important variable in the equation is %A, the "wetted"surface area of the tank, which is dependent upon several factors.

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Figure 2. *Average Relative Humidity (%), January*

"Wetted" Surface Area Determinants

The greater the physical size of the tank, the more outside surface area it has, directly increasing its vaporization capacity. However, only that portion of the tank in contact with the liquid can transfer heat. This area is found from the volumetric percentage of liquid in the tank and can be easily determined from the liquid level gauge. The liquid level itself is affected by two other factors: (1) the ratio of the tank's length to its outside diameter, and, less importantly, (2) whether the tank heads are flat, elliptical, or hemispherically shaped. Table 1 demonstrates the effect of the various parameters on the percentage of wetted surface area.

Table 1. *Wetted Percentage of Total Tank Surface Area*

HEAD TYPE	LENGTH TO DIAMETER RATIO	VOLUME PERCENT FULL		
		25%	33%	50%
Flat	2:1	34.41	39.82	50.0
	4:1	35.46	40.54	50.0
	6:1	35.86	40.82	50.0
Elliptical	2:1	34.35	39.80	50.0
	4:1	35.45	40.55	50.0
	6:1	35.86	40.83	50.0
Hemispherical	2:1	34.29	39.77	50.0
	4:1	35.44	40.56	50.0
	6:1	35.87	40.85	50.0
Total surface area for a cylindrical container with hemispherical heads = overall length x outside diameter x 3.14. Total surface area for a cylindrical container with other than hemispherical heads = (overall length + 0.3 outside diameter) x outside diameter x 3.14.				

Temperature Differential

Another important consideration in the vaporization equation is the temperature differential between the liquid in the tank and the atmosphere. As mentioned previously, this differential determines the amount of heat available to the liquid. Not all of the heat, however, can be used. A humidity correction factor limits the amount of available heat that can be extracted from a given temperature differential.

As air temperature decreases and relative humidity increases, the usable temperature difference reaches a minimum. This is because the cold air surrounding the tank becomes saturated with water vapor at high humidity levels, making precipitation form on the slightly colder tank surface. At winter temperatures the precipitation immediately turns into frost. As can be seen from Table 2, there is only 1°F temperature difference between the air and the tank with a -30°F air temperature and 90% relative humidity. Going the opposite direction, a low humidity of 20% together with an outside temperature of 40°F gives 35 degrees of usable temperature differential.

Take, for example, a 500-gallon tank with hemispherical heads and an overall length-to-diameter ratio of 4:1 that has a total surface area of 97 ft.^{2}. The tank is located in a region where the lowest average temperature is -10°F and the average relative humidity is 80%. (See Figure 2

Table 2. *Difference Between Air Temperature and Temperature of Frost Formation*

AIR TEMPERATURE, °F	RELATIVE HUMIDITY							
	20%	30%	40%	50%	60%	70%	80%	90%
-30	- - -	- - -	- - -	- - -	8.0(1)	5.0(1)	2.5(1)	1.0(1)
-25	- - -	- - -	15.0(1)	11.0(1)	8.0(1)	5.0	3.0	1.5
-20	- - -	20.0(1)	15.0(1)	11.5(1)	8.5	5.0	3.0	1.5
-15	- - -	20.0(1)	15.5	12.0	8.5	5.5	3.0	1.5
-10	27.5(1)	20.5	16.0	12.0	9.0	6.0	3.0	1.5
-5	28.0(1)	21.0	16.0	12.0	9.0	6.0	3.5	2.0
0	29.0	21.5	16.5	12.5	9.0	6.0	4.0	2.0
5	29.5	22.0	17.0	13.0	9.0	6.0	4.0	2.0
10	30.0	22.5	17.0	13.0	9.5	6.5	4.0	2.0
15	31.0	23.0	18.0	13.5	10.0	7.0	4.0	2.0
20	31.5	24.0	18.0	14.0	10.0	7.0	4.0	2.0
25	32.5	24.0	19.0	14.5	10.5	7.5	4.5	2.0
30	33.0	25.0	19.5	15.0	11.0	8.0	5.0	3.0
35	34.0	26.0	20.0	16.0	11.5	8.5	5.0	3.0
40	35.0	27.0	21.0	16.5	12.0	9.0	8.0	8.0

1. If the full temperature difference is used in these cases, the minimum tank pressure may be too low for satisfactory performance. Reprinted with permission from *A Practical Guide to LP-Gas Utilization*.

for a map showing typical relative humidities for various regions of the United States.) Under these conditions, how much fuel can the tank vaporize without frost build-up if it is one-quarter full?

Using the equation, $Q = U \times \%A \times (T_1 - T_2)$, we find:

$U = 2$

$\%A = 97 \text{ ft.}^2 \times 35.44$
(% of total surface area wetted from Table 1)

$(T_1 - T_2) = 3$
(°F, usable temperature difference from Table 2)

Plugging these numbers into the equation produces a Q value of 206.3 Btuh. Table 3 shows the Btu's needed to vaporize 1 pound of propane at various temperatures. At -13°F (-10°F atmospheric + -3°F usable temperature difference) it can be interpolated from that table that it takes 174.25 Btu to vaporize 1 pound of liquid propane.

Therefore:

206.3 Btuh -174.25 Btu/lb = 1.18 lbs/hr (vaporized fuel)
Vaporized propane = 21,591 Btu/lb
1.18 lbs/hr x 21,591 Btu/lb = 25,562 Btuh
(the amount the tank can vaporize under these conditions)

If the 25,562 Figure seems exceptionally low, it's because the high humidity limits the available heat range to a scant 3 degrees for continuous service. Also, the wetted surface area of the tank is small when it is only one-quarter full. Under intermittent loading, the capacity for the tank might be three to four times greater.

Vaporization Capacities

Tables 4 and 5 are generalized listings showing the vaporization capacities of standard size tanks of the 4:1 ratio, one-quarter full, and at 40% and 80% relative humidities. The tables show maximum continuous withdrawal rates that can be achieved without tank frosting taking place. Note the dramatic reduction in tank vaporization capacity with the 80% relative humidity (Table 5).

In sizing tanks to prevent a winter time overload, it is apparent that four factors should be prime considerations

1. The size of the tank
2. The lowest normal temperature expected
3. The mean relative humidity
4. The lowest percentage volume level the tank will be allowed to reach

This means that for older installations merely maintaining a higher fuel level in the tank will appreciably boost the vaporization rate. When all of the elements of the capacity equation are given proper consideration, the LP-gas system is better prepared to operate effectively through its most challenging period.

Table 3. *Heat (BTU) Needed to Vaporize 1 pound propane*

TEMPERATURE, °F								
40	**30**	**20**	**10**	**0**	**-10**	**-20**	**-30**	**-40**
159.0	162.0	165.0	168.0	170.5	173.5	176.0	179.0	181.5

Table 4. *Tank 25% Full at 40% Relative Humidity Maximum Continuous Withdrawal Rate (BTUH) Without Tank Frosting If Lowest Outdoor Temperature (24 Hour Average) Reaches:*

TANK SIZE, GALLONS	LOWEST OUTDOOR TEMPERATURE (24 HOUR AVERAGE), °F							
	40	**30**	**20**	**10**	**0**	**-10**	**-20**	**-30**
150	84 740	77 280	70 500	65 580	62 740	59 910	55 400	29 430
250	113 570	103 570	94 480	87 890	84 090	80 300	74 260	39 440
500	188 760	172 150	157 040	146 080	139 760	133 460	123 420	65 550
1000	336 230	306 640	279 720	260 200	248 940	237 730	219 840	116 760

1. For a tank at 1/3 full, multiply Btuh values by 1.144.
2. For a tank at 1/2 full, multiply Btuh values by 1.41.

Table 5. *Tank 25% Full at 80% Relative Humidity Maximum Continuous Withdrawal Rate (BTUH) Without Tank Frosting If Lowest Outdoor Temperature (24 Hour Average) Reaches:*

TANK SIZE, GALLONS	LOWEST OUTDOOR TEMPERATURE (24 HOUR AVERAGE), °F							
	40	**30**	**20**	**10**	**0**	**-10**	**-20**	**-30**
150	33 000	20 360	16 020	15 760	15 510	11 460	11 290	9 270
250	44 230	27 290	21 480	21 120	20 790	15 360	15 130	12 420
500	73 510	45 360	35 700	35 100	34 550	25 530	25 150	20 640
1000	130 940	80 790	63 580	62 530	61 540	45 480	44 800	36 770

1. For a tank at 1/3 full, multiply Btuh values by 1.144.
2. For a tank at 1/2 full, multiply Btuh values by 1.41.

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