Pump Starvation—Cause, Effect and Cure

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What is meant by "pump starvation"?

When the intake of liquid to a pump is less than the capacity of the pump to discharge, this condition is frequently referred to as "pump starvation."

What is the cause of pump starvation?

It is caused by any of a number of conditions which restrict the flow of liquid to the pump, such as an inadequate size of the inlet piping, or an insufficient head pressure to force the liquid through the inlet piping, and its necessary fittings, to the pump.

Would not pump suction be effective in drawing liquid in sufficient quantity to fill the pump capacity regardless of some restriction in the inlet line?

Pump suction is effective to a degree in pumping water or oil, but this does not work out with such liquids as butane or propane, which are being handled at their boiling points. Even a slight reduction of pressure in the suction line to less than the vapor pressure established in the supply tank, will cause the liquid to boil or to "open up into gas," as we say. Such suction pressure reduction in the intake line results in what is sometimes called a "foaming intake."

What effect does this have on the pump capacity?

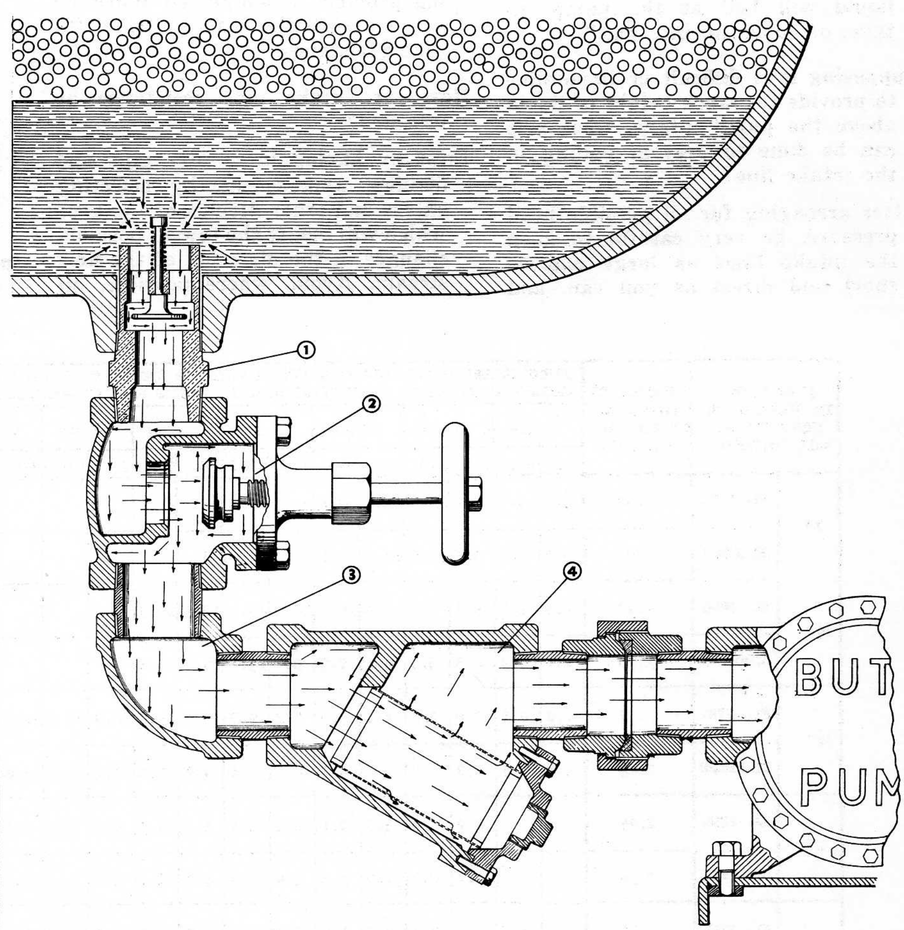
Every bubble of gas at the pump intake naturally displaces a like volume of liquid. If the intake were half gas in volume, we would discharge approximately half as much liquid as we would if the intake were solid liquid.

What is the best way to avoid this capacity reduction?

In the first place, since it is often impossible to avoid a considerable resistance to fluid flow in the intake line, it is most important to provide as much height of the tank liquid level above the pump intake as may be practicable.

It is difficult to see why the addition of a few feet of height of the liquid level above the pump would help much when the liquid is already under a vapor pressure of 50 to 150 lbs. in the tank. Doesn't this tank pressure help to force the liquid into the pump?

Suppose you are handling 100% propane at a tank temperature of say 80° Fahrenheit, your tank gage will register 128 lbs. This figure you can find on your temperature-pressure charts, and this is the pressure at which the liquid will stop boiling at that particular temperature. If, under these conditions you were to draw off a little gas, enough even to drop the pressure just 1 lb., or to 127 lbs. on your tank gage, the liquid in the tank would at once start to boil and to give off additional gas or vapor so as to bring the pressure on your gage right back to the 128 lbs. This, of course, is assuming that the temperature remained constant.



This drawing shows a pump intake assembly made up of (1) 3-in. excess flow valve; (2) 3-in. globe valve; (3) 3-in. elbow, and (4) 3-in. strainer, all of standard makes. It is worthy of note that the restricted flow area in the excess flow valve, just below the valve seat, is less than one-half the area of the 3-in. pipe, and that the excess flow valve as well as the globe valve become a serious flow impediment due to the numerous changes in fluid flow direction. The various units shown are drawn to scale.

Now, for the same reason, if the pressure in the intake line is reduced 1 lb., or more likely several pounds, in drawing the liquid to the pump by suction, the same boiling of the fluid results, only this time the bubbles are formed in the suction line instead of in the tank.

How does the height of liquid level above the pump stop this trouble?

If the liquid level is higher, say by several feet, than the pump intake, then the pressure at the pump will be just that much greater than the registered pressure in the tank. This added pressure amounts roughly to 1 lb. for every 4 ft. of liquid height for butane or propane, so that if the liquid level were 4 ft. above the pump intake and our gage registered 128 lbs. in the tank, the pressure at the pump would be 129 lbs. This 1 lb. of pressure is then available to force the liquid into the pump without drawing the pressure down to where the liquid will boil at the pump intake, or "open up into gas."

Supposing it is difficult or impossible to provide for much height of liquid above the pump intake, what else can be done to prevent boiling in the intake line?

After arranging for all possible head pressure, be very careful to keep the intake lines as large and as short and direct as you can, and pay particular attention to having the fewest possible changes of direction of flow as can be arranged.

Is it more important to have large and direct lines to a pump mounted on a tank truck?

Only because on a tank truck it seems quite difficult to provide for much inlet head. In other words, it is not practical on a tank truck to raise the tank much above the truck frame because of the importance of keeping a low center of gravity, and so avoid a top-heavy load. On the other hand, the pump cannot be mounted too low on account of road clearance. Therefore it is seldom possible to have the pump intake more than a foot, or perhaps two feet at the most, below the tank bottom.

How then can an adequate flow of liquid be insured?

Only by careful attention to the piping problem as suggested above, so as to assure the least possible intake resistance.

How can intake pipe resistance be lessened?

First by having large size pipe and fittings, and second by selecting valves and other fittings of the type which will insure the fewest possible changes in the direction of the flow stream. Avoid, where possible, all fittings with flow areas which are restricted to less than the full pipe area.

What size pipe should be used?

It would be a very good rule if the inlet lines for every butane and propane pumping installation could be kept large enough so the flow velocity through the pipe and fittings never exceeded a rate of 4 to 5 ft. per second.

What size piping would it take to carry out this rule, say on an installation handling 50 gals. per minute?

Table I has been prepared to show at what velocity in feet per second liquid must flow in various size pipes to carry a certain number of gallons per minute discharge. From this table, we see that were we to adopt a 2-in. standard strength pipe for capacity of 50 gals. per minute, we would have a flow velocity of 4.8 ft. per second, but if we used extra strong pipe, which is usually required as a safety measure, this would raise the flow velocity to 5.4 ft. per second. The table also shows that if we could provide 2½-in. piping, the velocity would go down to 3.8 ft. per second, even if extra strength pipe were used.

Just why is a velocity of 4 ft. per second so much better than 5 or 6

TABLE 1

PIPE SIZE IN STANDARD OR EXTRA STRONG WALL THICKNESS		INTERNAL OR FLOW AREA OF PIPE IN SQ. INS.	FIRST COLUMN SHOWS FLOW VELOCITY IN FEET PER SEC. THROUGH PIPE TO DELIVER GALLONS PER MIN. REQUIRED. SECOND COLUMN SHOWS THEORETICAL HEAD IN INCHES USED IN ACCELERATION OF LIQUID TO VELOCITIES SHOWN.																			
			10 GPM		20 GPM		30 GPM		40 GPM		50 GPM		60 GPM		70 GPM		80 GPM		90 GPM		100 GPM	
			VEL.	HEAD	VEL.	HEAD	VEL.	HEAD	VEL.	HEAD	VEL.	HEAD	VEL.	HEAD	VEL.	HEAD	VEL.	HEAD	VEL.	HEAD	VEL.	HEAD
1"	EX. STR.	.72	4.4	3.7	8.9	14.9	13.4	33.6														
	STANDARD	.86	3.7	2.6	7.5	10.6	11.2	23.6														
1¼"	EX. STR.	1.28	2.5	1.2	5.0	4.7	7.5	10.6	10.0	19.0	12.5	29.0										
	STANDARD	1.50	2.1	0.9	4.3	3.5	6.4	7.7	8.5	13.6	10.7	21.6										
1½"	EX. STR.	1.77	1.8	0.6	3.6	2.5	5.4	5.5	7.2	9.7	9.0	15.2	10.9	22.0	12.6	30.0						
	STANDARD	2.04	1.6	0.5	3.2	1.9	4.7	4.2	6.3	7.4	7.9	11.8	9.4	16.6	11.0	23.0	12.6	30.0				
2"	EX. STR.	2.95			2.2	.9	3.3	2.1	4.3	3.5	5.4	5.5	6.5	8.0	7.6	10.8	8.7	14.2	9.8	18.0	10.9	22.0
	STANDARD	3.36			1.9	0.7	2.9	1.6	3.9	2.9	4.8	4.4	5.8	6.4	6.8	8.5	7.8	11.4	8.7	14.0	9.7	17.6
2½"	EX. STR.	4.24			1.5	0.4	2.3	1.0	3.0	1.7	3.8	2.7	4.5	3.8	5.3	5.3	6.0	6.8	6.8	8.6	7.5	10.6
	STANDARD	4.79			1.3	0.3	2.0	0.7	2.7	1.4	3.3	2.0	4.0	3.0	4.7	4.2	5.3	5.4	6.0	6.8	6.7	8.5
3"	EX. STR.	6.61					1.4	0.4	2.0	0.7	2.4	1.2	2.9	1.6	3.4	2.2	3.9	2.9	4.4	3.7	4.8	4.4
	STANDARD	7.39					1.3	0.3	1.7	0.6	2.2	0.9	2.6	1.3	3.0	1.7	3.5	2.3	3.9	2.9	4.3	3.5
4"	EX. STR.	11.50							1.1	0.2	1.4	0.4	1.7	0.6	2.0	0.7	2.2	1.0	2.5	1.2	2.8	1.5
	STANDARD	12.73							1.0	0.2	1.3	0.4	1.6	0.5	1.8	0.7	2.0	0.8	2.4	1.0	2.6	1.3

or even 8 ft. per second, which is often considered satisfactory for water or even gasoline?

The figures shown in Table I in the columns marked "Head," opposite the velocity rates, show the amount of head energy which is consumed to accelerate the fluid to the necessary velocity. The figures are based on the theoretical acceleration. Actual discharge rates under varying conditions may be considerably less than these figures would indicate, depending principally on the shape of the passages involved. However, this table will help to a better understanding of the problem, and gives a good indication of the comparative amount of energy in inches of head pressure which will be used up in accelerating liquid in the pipe and fittings to the various required velocities, in feet per second. From these figures, we see that to initially accelerate a liquid to a velocity of 5.4 ft. per second for the delivery of 50 GPM through 2-in extra strong pipe, will take 5½-in. of head energy. However, to deliver twice as much liquid, or 100 GPM, through this same pipe, the velocity would be doubled. According to our table, to deliver 100 GPM through 2-in. extra strong pipe, the velocity would be 10.9 ft. per second, and the liquid head consumed would be 22 in. instead of 5½ in., or four times as much. On the other hand, we could double the through-put volume by changing the flow area to twice its size. In other words, a 3-in. pipe would more than double the flow and would do this with less than the original 5½ in. of head.

Is this the reason that larger pipes are important when there is a limited height of liquid?

Yes, this is it, but if the liquid only had to be accelerated once, the size of piping and the flow areas of fittings would not be of nearly so much importance. As a matter of fact, this liquid has to be accelerated not once, but usually many times, before it gets from the tank to the pump.

Why is this?

Suppose we assume it takes 3 in. of head energy to start liquid flowing from our tank into a 2-in pipe at 4 ft. per second. Just as soon as this liquid hits a 90° elbow, practically all this flow velocity energy is lost.

Why is this?

Because the liquid does not glide smoothly around an ordinary 90° pipe elbow, as one might think. Liquid, like any other matter, does not readily change its direction of motion. In fact it is found by tests, that practically 100% of the energy originally acquired by the liquid has been lost in passing around a standard 90° elbow, and a new 3 inches of head must be allowed to again accelerate the fluid in the new direction.

Does a 45° elbow cause the same resistance?

No, we usually allow about one-half of this loss for a 45° degree elbow.

Does a globe valve cause as much resistance as a 90° elbow?

Yes, here is where we begin to get into real trouble. In fact, it is found by actual test, that a globe valve of the usual standard type, may cause not just as much, but even 10 times as much flow resistance as a 90° elbow of the same designated pipe size.

Why is this?

It is only necessary to examine the flow path through any globe valve to see that several complete changes of flow direction occur in the passage of the fluid. Each of these changes of flow direction can be figured to add an extra 3 in. of head energy or more, to maintain the flow capacity.

Why do you say more?

Because the flow areas through a standard globe valve are often reduced as much as to half of the normal pipe cross sectional area. So with each turn in direction, and with the flow area reduced to half, we would have lost an acceleration force equal to 8 ft. per second instead of 4 ft. This 8 ft. per second velocity would, according to our table, then absorb 12 in. of our head energy instead of 3 in. It is for this reason that a globe valve does actually cause as much as 10 times the resistance of a 90° elbow, and so plays havoc with any attempt to get by with our limited head pressure and still deliver solid liquid to the butane pump.

What can be done about this?

The substitution of gate valves or plug valves when possible in the service, is the best answer. These valves, by permitting straight through flow, eliminate practically all these resistance losses except perhaps for some flow area reduction in certain types of plug valves.

Why are not plug or gate valves more generally used?

Probably because they are often quite troublesome to keep tight. Aside from this, their use is very much to be advised.

AMOUNT OF REDUCTION OF PRESSURE AT PUMP INLET BELOW PRESSURE IN TANK	REDUCTION IN POUNDS	1/4#	1/2#	3/4#	1#	1 1/4#	1 1/2#	1 3/4#	2#	2 1/4#	2 1/2#	2 3/4#	3#
	REDUCTION HEAD IN FT.	1'	2'	3'	4'	5'	6'	7'	8'	9'	10'	11'	12'
PROPANE AT TEMP. OF	110°F.	.5	1.2	1.9	2.6	3.3	4.0	4.6	5.2	5.7	6.2	6.7	7.2
	70°F.	1.8	3.2	4.5	5.8	7.1	8.4	9.6	10.8	12.0	13.1	14.2	15.2
	30°F.	4.0	8.0	11.0	14.0	17.0	2.0	22.5	25.0	27.0	29.0	31.0	33.0
ISOBUTANE AT TEMP. OF	110°F.	4.0	7.5	11.0	14.5	17.5	20.5	23.0	25.5	28.0	30.0	32.0	34.0
	70°F.	8.5	16.0	23.0	29.0	34.0	38.0	42.0	45.5	48.5	51.0	53.0	55.0
	30°F.	19.0	34.0	46.0	55.0	60.0	64.0	67.5	70.5	73.0	75.0	77.0	78.5
N-BUTANE AT TEMP. OF	110°F.	6.0	11.0	15.5	19.5	23.0	26.0	29.0	32.0	34.5	37.0	39.5	42.0
	70°F.	12.0	23.0	33.0	41.5	47.0	52.0	56.0	59.0	62.0	64.5	67.0	69.0
	30°F.	30.0	46.0	56.0	62.5	67.0	70.5	74.0	77.0	79.0	80.5	82.0	83.0

Table 2. The table above shows the approximate pump loss in per cent of delivery capacity which may be expected when the pressure in the inlet line at the pump is reduced by suction to below the pressure registered in the supply tank. This loss will be in accordance with the volume of vapor which may be formed and which displaces an equal volume of liquid.

These figures emphasize the advantage to be derived from providing a fluid level in the storage tank as high above the pump inlet as possible, or when this cannot be done, the importance of having a large size inlet line with oversize pipe fittings and the fewest possible changes in direction of flow, as explained in this article.

EXAMPLE—If propane is to be pumped at 70° F. under a suction pressure reduction at the pump intake of 3 lbs. below the tank vapor pressure, what loss in pump capacity may be anticipated?

ANSWER—In the table under propane at 70° F., find the figure in the column for 3 lb. reduction, which is 15.2. This indicates a loss of 15.2% in pump output capacity. Other factors may add to this loss but for the single item of a starved suction line, a pump of 50 GPM capacity would be reduced by 15%, or to 42.5 GPM discharge.

Does an excess flow valve offer a serious flow impediment?

Yes, the standard type of excess flow valve causes about the same, if not a greater, impediment than the globe valve and can readily consume many feet of head energy in passing their rated capacity.

What can be advised to overcome this difficulty?

Since the resistance which these valves cause is dependent on the velocity of flow through restricted areas, as well as to numerous changes of flow direction, the best remedy is to install as large an excess flow valve as may be permitted. As previously stated, doubling the flow area will theoretically reduce to one-fourth, the amount of head energy lost for each change of direction.

Assuming that with all due care in eliminating flow bends and restricted areas, it becomes quite impossible to expect the delivery of the required flow to the pump by gravity alone, what loss in output may be expected under such conditions?

This reduction in capacity can be quite definitely computed but will depend upon the type of fluid handled, the temperature at which it is being pumped, and the pounds or feet of suction pressure reduction which becomes necessary to supply the pump capacity.

Is there any simple way to determine this loss?

Table II is intended to give an approximate indication of the pump capacity which will be lost through the suction pressure reduction necessary to draw the liquid to the pump. This subject will be covered in greater detail in a later article when we will provide more data on which to compute these losses.

Since avoidance of pump starvation seems to be so very important in effecting full pump delivery, how can we summarize the principal items to which close attention should be given in a butane or propane pump installation?

1. Provide inlet piping and fittings of large cross-sectional area.
2. Avoid all sharp bends in the piping layout.
3. Select all valves and fittings with a view to straight through flow where possible. Otherwise, oversize valves and fittings are to be advised.
4. Provide for as much gravity head as can be arranged, by raising the tank and lowering the pump to keep the liquid level as high as practical above the pump intake.

Most of the suggestions above have related to the pump inlet line. Should the outlet line also be planned in the same way for free flow capacity?

It seems very important to use a great deal of care in getting butane or propane into the pump. This is due to the unstable condition of this type of fluid which must be handled at its boiling point. However, when solid liquid, free from gas bubbles, can be delivered to the pump, it usually is not difficult with a good pump to develop any reasonable necessary outlet pressure to care for ordinary pipe resistance, or to force the liquid against the usual vapor pressure differentials encountered.

Are not many butane and propane pumps operating successfully where the piping problem has not been too carefully worked out?

Yes, thousands of pumps are installed apparently without too much consideration for their most successful performance. Their operation is usually entirely satisfactory where maximum delivery is not too important. However, when the principles involved are better understood, pumps can be installed to operate with far greater efficiency, to last longer, and to give generally more satisfactory service.