PUMPING FROM DRAFT

D.F. Thomas, P.E.

January, 1983

WATEROUS

F–2093

PUMPING FROM DRAFT

1. WHAT IS A PUMP?

Most of us who were born before World War II remember the old hand pumps which were on every farm and in many kitchens, before the days of the REA. The modern centrifugal pump used on fire pumpers today is very different from those pumps, but it still works in the same basic way—a certain quantity (gallons) of fluid (water) is moved each unit of time (minute) from one pressure level (suction pressure) to a higher pressure level (discharge pressure). If water is to be moved from a source at atmospheric pressure (a stream, lake, or reservoir) which is below the level of the pump, the pump will have to draft the water; drafting consists of creating a pressure lower than atmospheric pressure ("vacuum") at the pump so that water will flow from the source to the pump. If the water must be forced to a level higher than the pump, or through a length of pipe, or hose, or through a nozzle, then the pump must add pressure to the water so that the discharge pressure is greater than atmospheric pressure.

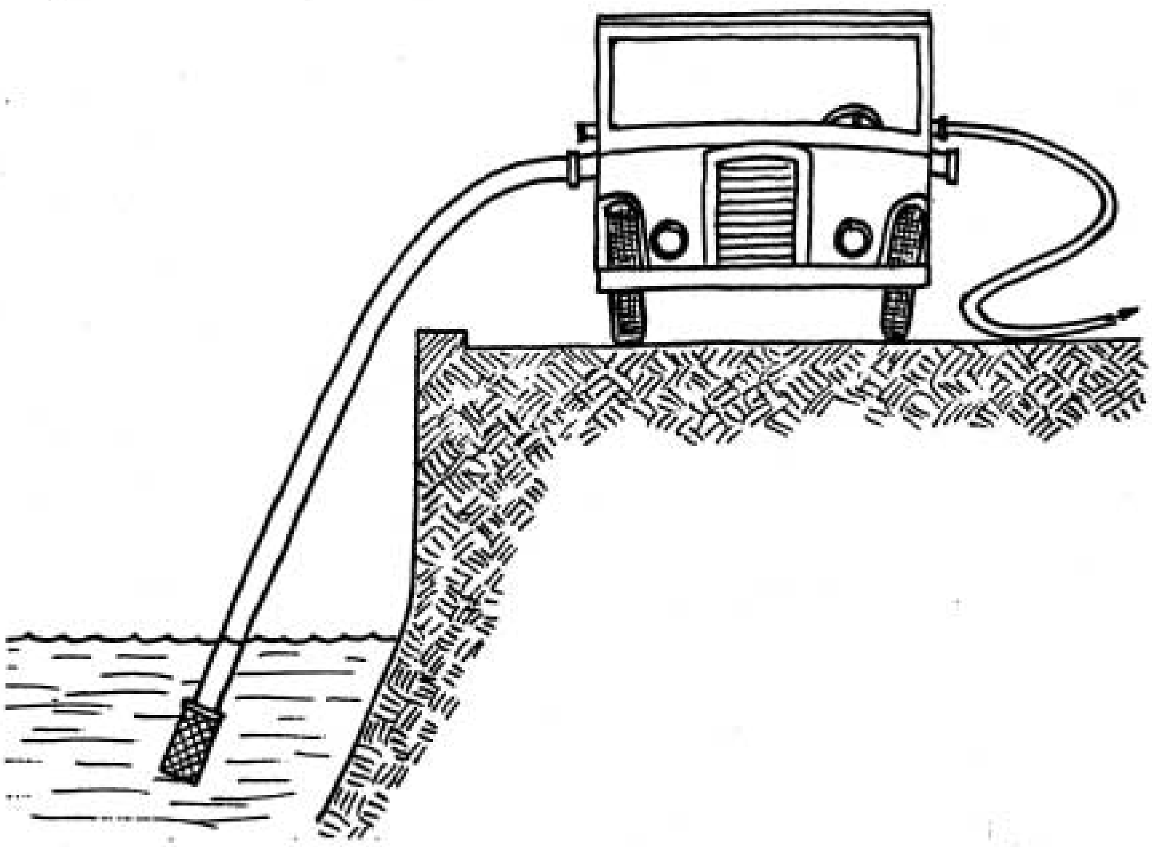

Fig. 1

Fig. 1 shows a pump drafting from a pond thru 20 feet of suction hose. The air in the atmosphere is pushing down on the surface of the water due to its weight; this is the "atmospheric pressure" and at sea level it averages 14.7 pounds per square inch. In order to get the water in the pond to flow to the pump, the pressure at the pump inlet must be lower than the atmospheric pressure, or, in other words, a "partial vacuum". (A "perfect" vacuum never exists in nature but would if all air and other matter could be removed from a chamber.) Initially, this is done by "priming", or removing some of the air from the pump and suction hose with a priming pump or other priming device. When the main pump has been primed but before it begins to operate, the "vacuum" at the pump inlet will be equal to the static "lift", or the vertical distance from the surface of the water to the centerline of the pump inlet. With the pump operating, the friction caused by the water flowing through the suction strainer and hose will cause the vacuum to increase, so that the higher the flow, the higher the vacuum will be. A centrifugal pump can operate very well with a partial vacuum at the inlet, but if air is allowed to enter the suction the pump "loses prime" and ceases to pump water. Or, if it is operated at too high a lift, or with too small or too long a suction hose, it will "cavitate" and operate erratically or stop pumping altogether. (See below.)

2. NET PUMP PRESSURE

With a hand pump, which merely lifts water from the underground reservoir (well) until it spills out the spout as shown in Fig. 2, the inlet pressure is always below atmospheric pressure (vacuum) and the discharge pressure is practically the same as atmospheric pressure. So net pump pressure, or the difference between the inlet pressure and the discharge pressure, is the same as the inlet pressure if you consider atmospheric pressure as zero and inlet pressure as a vacuum.

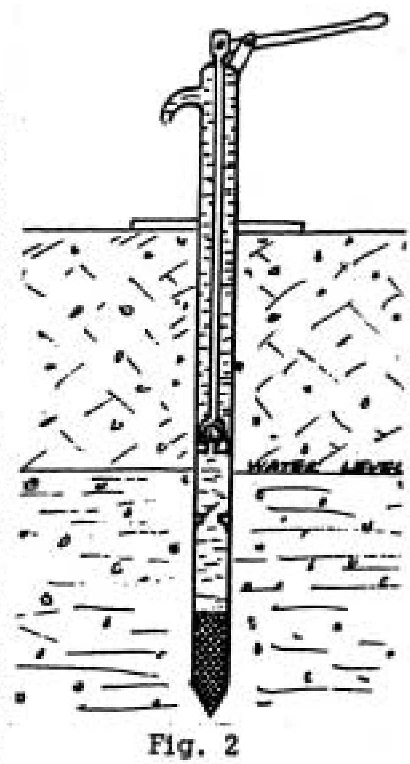

Fig. 2

With a fire apparatus pump which is drafting and discharging through one or more outlets which have hoses attached and nozzles at the ends of the hoses, as shown in Fig. 1, the discharge pressure will usually be at least 100 pounds per square inch above atmospheric pressure. This is registered on a gage connected to the pump discharge manifold, and is measured in "pounds per square inch, gage" (psig). The net pump pressure is the negative inlet pressure (vacuum) added to the discharge pressure. The inlet pressure may be measured by a gage such as a mercury manometer or vacuum gage. If the reading is in inches of mercury it must be converted into pounds per square inch (one pound per square inch equals 2.035 inches of mercury). If desired, the inlet pressure may be determined from Table 3-1.2.2(e) (friction and entrance loss) shown in NFPA 1901 (Fig. 3) by adding the proper value from the table to the static lift. The net pump pressure is expressed in "pounds per square inch" (psi), so the friction and entrance loss and the static lift must be converted to psi (one pound per square inch equals 2.31 feet of water).

Table 3–1.2.2(e). Friction and Entrance Loss in 20 ft. of Suction Hose, Including Strainers

Flow Rate GPM	Suction Hose Size (Inside Diameter)													
	4 in.		4–1/2 in.		5 in.		6 in.		2 – 4–1/2 in.		2 – 5 in.		2 – 6 in.	
	ft water	in. Hg	ft water	in. Hg	ft water	in. Hg	ft water	in. Hg	ft water	in. Hg	ft water	in. Hg	ft water	in. Hg
500	5.0 (1.3)	4.4	3.6 (0.8)	3.2	2.1 (0.4)	1.9	0.9 (0.2)	0.8						
350	2.5 (0.7)	2.1	1.8 (0.4)	1.6	1.0 (0.2)	1.0	0.4 (0.1)	0.4						
250	1.3 (0.4)	1.1	0.9 (0.3)	0.8	0.5 (0.1)	0.5	0.2 (0.1)	0.2						
750	11.4 (2.9)	9.8	8.0 (1.6)	7.1	4.7 (3.9)	4.2	1.9 (0.4)	1.7						
525	5.5 (1.5)	4.9	3.9 (0.8)	3.4	2.3 (0.5)	2.0	0.9 (0.2)	0.8						
375	2.8 (0.7)	2.5	2.0 (0.4)	1.8	1.2 (0.2)	1.1	0.5 (0.1)	0.5						
1000			14.5 (2.8)	12.5	8.4 (1.6)	7.4	3.4 (0.6)	3.0						
700			7.0 (1.4)	6.2	4.1 (0.8)	3.7	1.7 (0.3)	1.5						
500			3.6 (0.8)	3.2	2.1 (0.4)	1.9	0.9 (0.2)	0.8						
1250					13.0 (2.4)	11.5	5.2 (0.9)	4.7	5.5 (1.2)	4.9				
875					6.5 (1.2)	5.7	2.6 (0.5)	2.3	2.8 (0.7)	2.5				
625					3.3 (0.7)	2.9	1.3 (0.3)	1.1	1.4 (0.3)	1.2				
1500							7.6 (1.4)	6.7	8.0 (1.6)	7.1	4.7 (0.9)	4.2	1.9 (0.4)	1.7
1050							3.7 (0.7)	3.3	3.9 (0.8)	3.4	2.3 (0.5)	2.0	0.9 (0.3)	0.8
750							1.9 (0.4)	1.7	2.0 (0.4)	1.8	1.2 (0.2)	1.1	0.5 (0.1)	0.5
1750							10.4 (1.8)	9.3	11.0 (2.2)	9.7	6.5 (1.2)	5.7	2.6 (0.5)	2.3
1225							5.0 (0.9)	4.6	5.3 (1.1)	4.7	3.1 (0.7)	2.7	1.2 (0.3)	1.1
875							2.6 (0.5)	2.3	2.8 (0.6)	2.5	1.6 (0.3)	1.4	0.7 (0.2)	0.6
2000									14.5 (2.8)	12.5	8.4 (1.6)	7.4	3.4 (0.6)	3.0
1400									7.0 (1.4)	6.2	4.1 (0.8)	3.7	1.7 (0.3)	1.5
1000									3.6 (0.8)	3.2	2.1 (0.4)	1.9	0.9 (0.2)	0.8

Note: Figures in parentheses indicate increment to be added or subtracted for each 10 ft. of hose less than or greater than 20 ft.

Figure 3.

For example, suppose the pumper shown in Figure 1 is drafting from an 8 foot lift through 0 feet of 5 inch suction hose, pumping 850 gpm at 128 psig. From Figure 3, we see that at 750 gpm the friction and entrance loss would be 4.7 feet of water, and at 875 gpm it would be 6.5 feet; so we can estimate that at 850 gpm the loss would be 6.0 feet. We add this to the 8 foot lift to get a total (dynamic) lift of 14.0 feet and divide by 2.31 to get 6.06 psi vacuum:

Friction and Entrance Loss + Static Lift = Dynamic Lift

$$6 \text{ ft} + 8 \text{ ft} = 14 \text{ ft} \qquad \frac{14 \text{ ft}}{2.31} = 6.06 \text{ psi (vacuum)}$$

So net pump pressure is 128 psig plus 6 psi, or 134 psi.

If a fire apparatus pump is operating from a hydrant or in relay where the inlet pressure is above atmospheric pressure as shown in Figure 4, then the net pump pressure is the difference between the discharge pressure gage reading and the inlet pressure gage reading, but it is expressed in pounds per square inch (psi) just as it would be if the pump were drafting. If the pumper in Figure 4 is operating with an inlet pressure of 40 psig, and the discharge pressure is the same (128 psig) as the example illustrated in Figure1, the net pump pressure would be only 88 psi: 128 psig – 40 psig = 88 psi.

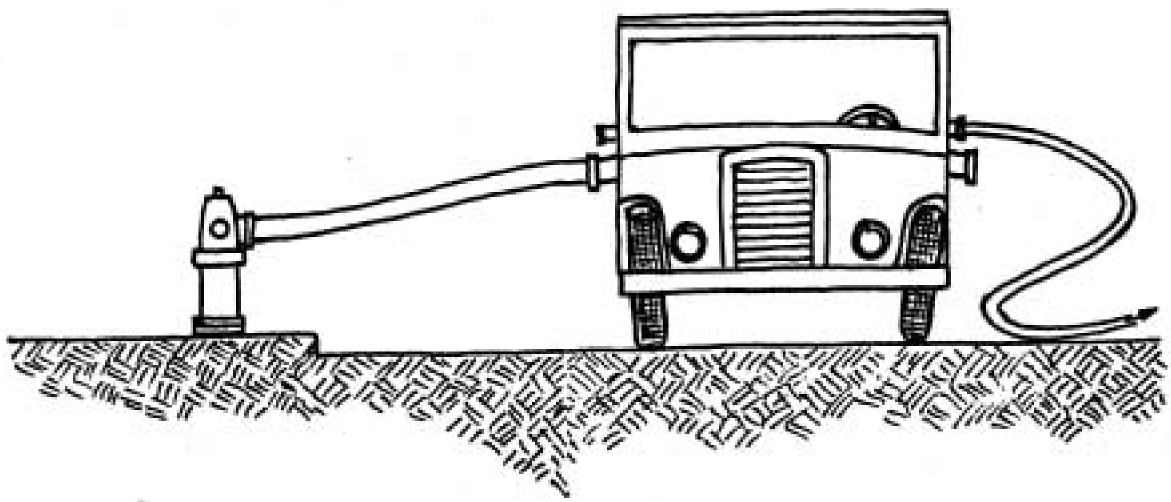

Fig. 4

3. EFFICIENCY, POWER, AND TORQUE

The term "efficiency", in engineering, has a very specific meaning: It is the ratio of the useful work accomplished to the amount of work expended. A centrifugal pump will operate at many different levels of efficiency depending on the net pump pressure and the capacity (gpm). A pump usually is most efficient when pumping near rated capacity and pressure. You can see that a two-stage, series/parallel pump in series ("pressure") will also operate at good efficiency at one-half its rated capacity, which is really the same as if it were at full rated capacity in parallel. As long as the pump is being supplied with water so that it does not "cavitate" (see below), the power required to pump any particular capacity (gpm) at any value of net pump pressure (psi) will remain very nearly the same regardless of the inlet and discharge pressures, as the efficiency will be the same.

The work accomplished per unit of time (water horsepower) will also be the same. The water horsepower is equal to the capacity in gpm multiplied by the net pressure in psi and divided by 1714. In the example used above (Fig. 1), where a pumper is pumping 850 gpm at 134 psi net pump pressure, the work accomplished would be 850 x 134 divided by 1714 or 66.5 horsepower. If the pump efficiency at this capacity and net pressure is 65 percent, the power necessary to drive the pump is 66.5 divided by 0.65 or 102.3 horsepower. If the pump had been pumping 850 gpm at 174 psig discharge pressure, but supplied from a hydrant at a suction pressure of 40 psig, then the net pressure would have been 134 psi, just as in the first case and the power required also the same—102.3 horsepower.

Torque is the term used for the "leverage" developed in the drive system; a force of 100 pounds, applied at the end of a 12 inch lever, develops 1200 pound-inches or 100 pound-feet of torque. Power is torque multiplied by rotational speed. In order to deliver a certain amount of power at 1500 rpm, an engine must develop a torque at 1500 rpm twice as high as if it were turning 3000 rpm. In other words, torque is a component of power; at any given speed, increasing the torque by 10% also increases the power by 10%, or with any particular value of torque, increasing the speed by 10% also increases the power by 10%. So, although torque can be multiplied by gearing or by other devices such as a hydraulic torque converter, when torque is multiplied but power is kept the same, the speed must be reduced. A truck engine which develops only 340 lb-ft torque at 2400 rpm can be geared down to develop the same torque at the driving axle at a given road speed as another engine which develops 680 lb-ft at 1200 rpm.

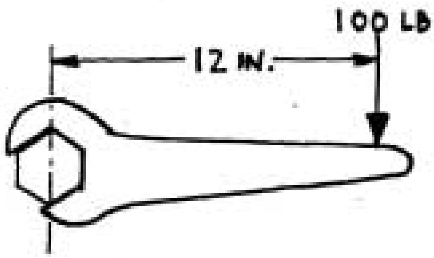

Fig. 5

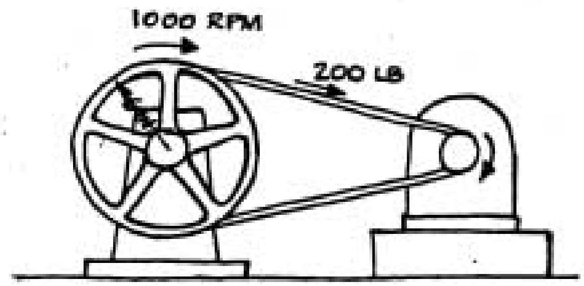

Fig. 6

4. NET POSITIVE SUCTION HEAD (NPSH)

This term is seldom used in the fire service but it is in wide use for industrial pumping applications. It is defined as "the total suction head in feet of liquid absolute determined at the suction nozzle and referred to datum less the vapor pressure of the liquid in feet absolute."[1] It is impossible to measure it directly, but it may be calculated from the reading of a gage attached to the pump inlet, the atmospheric pressure, and the water temperature. Every pump, at a given capacity and net pressure, has a value of required NPSH which depends on its design. The available NPSH must be equal to or greater than the required NPSH or the pump will "cavitate". Cavitation occurs when the water boils as it enters the pump impeller; the bubbles of vapor formed when cavitation occurs collapse when the pressure is increased within the impeller and can cause noise and mechanical damage. When the cavitation is severe, the capacity and pressure drop, and the torque required also drops; when the pump is driven by an internal combustion engine, as in fire apparatus, the reduced torque requirement allows the engine to speed up, and the pump is said to be "running away from the water."

Vapor pressure is the term used to express the volatility of a liquid; that is, the tendency of the liquid to evaporate. It increases with the temperature, and when it is equal to the prevailing pressure the liquid boils. The vapor pressure of water is 14.7 psi at 212°F so at sea level when the atmospheric pressure is normal, the temperature of water has to be raised to 212°F to cause it to boil. At higher altitudes, or when the atmospheric pressure is lower than normal, or when the prevailing pressure is lower than atmospheric (such as at the inlet to a pump), water will boil at a lower tempera-

---

[1] Hydraulic Institute Standards, 13th Edition, p. 52.

ture. For example, when the atmospheric pressure is 29.92 inches of mercury, but the pressure at the pump inlet is 18 inches of mercury vacuum, the absolute pressure at the inlet is 11.92 inches of mercury (29.92 minus 18.00), which is equivalent to 13.54 feet of water. If the water temperature is 100°F, its vapor pressure is 0.95 psi or 2.19 feet of water; this means that the NPSH available 13.54 less 2.19 or 11.35 feet. If the required NPSH is more than 11.35 feet, the pump will cavitate.

5. SOME PRACTICAL CONSIDERATIONS

The requirements of NFPA 1901 are based on conditions commonly found in North America and can be met with pumps and associated equipment which can be produced economically and mounted on truck chassis without difficulty. A 10 foot lift is higher than usually is required; in fact, in many localities it is difficult to find a place to draft where the lift is higher than 10 feet and still within practical reach of a pumper. Most localities are at altitudes less than 2000 feet. Where altitudes are higher than 2000 feet, or where lifts of 10 feet or higher are frequently necessary, the pumper can be operated at less than rated capacity, where the pump will have a lower required NPSH, and the available NPSH will be higher due to the reduced friction and entrance loss.

If it is very important that the pumper be capable of drafting full rated capacity at lifts higher than 10 feet, or at high altitudes with a lift of 10 feet, or at a distance away from the source so that more than 20 feet of suction hose must be used, then such special requirement should be considered when preparing the purchase specifications, so that the “specs” will require that the equipment to be bid and furnished will be capable of such performance. Such equipment is likely to be larger and heavier and therefore more costly than the equipment which would be bid to meet standard drafting requirements, and in addition may well be less efficient at the rated capacity so that a larger engine must be furnished.

6. PUMPER TESTS

Certification Tests are those tests performed at the apparatus manufacturer’s plant and witnessed by the representative of a certifying agency such as UL. They must be performed at draft, at a lift no higher than 10 feet. The ability of the pump to draft under the conditions given in NFPA 1901 is assured by the pump manufacturer’s certificate; this is usually based on a test of the pump itself under controlled suction conditions. The net pump pressure is determined by adding the discharge pressure gage reading to the reading of a manometer or suction pressure gage, or to the value of lift plus suction losses from the table published in NFPA 1901 (Figure 3).

Acceptance Tests are tests performed at the location where the pumper is to be used. If the drafting requirements in the purchase specifications are more stringent than those required by NFPA 1901 because of the necessity to draft at a lift higher than 10 feet, or at lifts near 10 feet at altitudes higher than 2000 feet, and have not been covered by the pump manufacturer’s certificate, a special drafting test should be performed. Care must be taken, however, to be sure that the actual atmospheric pressure, water temperature, and losses thru the suction hose and strainer are not abnormal; if the corrected atmospheric pressure is below 29 in. Hg, or the water temperature is over 90°F, the lift should be limited to 5 or 6 ft. If the vacuum reading when pumping rated capacity is more than it should be according to Figure 2, after considering the lift, the suction hose and strainer should be checked and replaced unless obvious defects are noted and repaired.

If the drafting requirements are not special, and if no convenient drafting site can be found, the acceptance tests can be performed by taking water from a hydrant in which case the net pump pressure is determined by subtracting the inlet pressure from the discharge pressure (the water used during the test will be wasted, and will have to be discharged into a drainage ditch or stream where it will flow away).

An acceptance test is the only practical way to determine if the engine power is sufficient to drive the pump, particularly if the altitude is significantly higher than that at the manufacturer's plant where the certification test was performed.

7. SUMMARY

Pumps are devices which move fluid, usually from a source at relatively low pressure through a discharge system to a destination at a higher pressure. The pressure added by the pump is net pump pressure. As long as inlet pressure is above the certain minimum value, so that the liquid does not boil before or as it enters the pump impeller, the value of the inlet pressure has no effect on the power required by the pump except as it affects the differential or net pump pressure.

With a given discharge pressure, the lower the inlet pressure (or the higher the inlet vacuum) the greater the net pump pressure will be and the greater the power requirement for a particular capacity (rate of flow). With a given net pump pressure (as in a pump test), the inlet pressure may vary widely without affecting the power requirement as the discharge pressure can be varied as necessary to maintain the net pump pressure at the specified value.

Special drafting requirements, more stringent than those in NFPA 1901, should be avoided as they will likely result in heavier, more expensive, and less efficient equipment than may be justified.