W A T E R O U S

Document Number	Issue Date	Rev. Date
F-1 168-1	**09/82**	**09/01/97**

How Climatic Conditions Affect Pumper Performance*

"Neither snow, nor rain, nor heat, nor gloom of night, stays these couriers from the swift completion of their appointed rounds."

Those well known words, first uttered by Herodotus, but best known as applied to Manhattan's postmen, could just as well (or perhaps better) be said with reference to firefighters around the world. While those various climatic conditions may not stay us from our "appointed rounds," they certainly may have an effect on how well we perform. Similarly, climatic conditions have a real effect on the performance of the mechanical devices we use to help us. Forgetting for the moment about frozen gage lines, ice-covered apparatus, and other miscellaneous effects on accessory equipment, let's turn our attention to the effects on the pumping performance of the pumper itself.

Atmospheric (barometric) pressure is probably the most important variable in our climate when it comes to predicting what tomorrow's weather will be, and it also is important in predicting how a pumper will perform. The variation in pressure which normally occurs in any given local area, while it most certainly helps us predict the weather conditions, also has an effect on pumper performance, although not usually an important one; but, when considering what performance in any one area rarely exceeds one inch of mercury, but the pressure drops about one inch for every 1000 feet of altitude--for altitudes above 2000 feet, therefore, this becomes an important consideration.

No one appreciates a very hot, nor a very cold day when he or she has to be outside working--especially in a firefighter's working clothes. The temperature of the air also affects how an internal combustion engine performs. Very hot weather seriously affects engine performance. Relatively cold temperatures help the engine develop power (although they can cause some problems, too, as anyone who lives in the northern part of the country can affirm).

Relative humidity and the temperature of the water which is to be pumped also affect pumper performance. Normally the effects of these are not important, but they can be, on occasion, and it is well to be aware of them.

The effects of variations in climatic conditions on the performance of the pump itself are not significant if the pump is supplied from a hydrant or other source which provides a positive pressure at the pump inlet. When drafting, or when pumping from the "booster" tank at relatively high rates, so that there is a "vacuum" in the pump inlet, they can be very important indeed. Pumps cannot "suck" water into their inlets' they can, however, create a zone of relatively low "absolute pressure" by exerting a force tending to move water out of this zone (the suction manifold) into the discharge manifold. The term "absolute pressure" refers to the pressure above a complete vacuum--normal atmospheric pressure at sea level is 29.9 inches of mercury, or 14.7 pounds per square inch, and is, therefore, 14.7 psia (pounds per square inch absolute). "Gage pressure" is the difference between the absolute pressure and atmospheric pressure, so when a discharge pressure gage reads "150," this indicates a pressure of 150 psig or, if the atmospheric pressure is 14.7 psia, an absolute pressure of 164.7 psia. The absolute pressure at the inlet of the pump must be a certain minimum value for the pump to perform properly; this value is different for different pumping conditions (capacity and net pressure), and is termed "net positive suction head," or "NPSH." The NPSH which exists is equal to the total absolute pressure of the water at the inlet, less the "vapor pressure" of the water. The vapor pressure varies with the temperature of the water, increasing with temperature, and is 14.7 psi at 212°F. In other words, if the required NPSH of a pump is 5 psi (it is usually expressed in feet of liquid), and the temperature of the water is 212°F, the pressure at the inlet must be at least 19.7 psia, or 5 psig, or the water will vaporize (boil) and the pump will "cavitate" and fail to pump properly.

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*By D. F. Thomas, P.E. (This paper was originally published in September, 1971. Only minor revisions have been made to the original. Also, edited versions of the original were published in the July, 1971, issue of Fire Engineering and the August, 1971, issue of Fire Command magazines.)

Anything which reduces the NPSH available at the pump inlet may prevent pumping the desired capacity. The higher the desired capacity, the higher the required NPSH will be. But, the *available* NPSH will be lowered by any or all of the following:

1. An increase in lift.
2. A decrease in suction hose or pipe diameter.
3. An increase in suction hose or pipe length (or extra fittings).
4. An increase in water temperature.
5. A decrease in atmospheric pressure.

You will note that the last two of these are climatic. Normally, water available for drafting is not warm enough to be of concern, but if a test pit is being used, or if the water in the booster tank is very warm, the water temperature can have a noticeable effect. The table below shows the vapor pressure of water at various temperatures; as stated above, the higher the vapor pressure, the lower the available NPSH.

Temperature, °F	V.P., psi
70	0.36
80	0.51
90	0.70
100	0.95
110	1.27
120	1.69
130	2.22

Variations in atmospheric pressure seldom cause a pumping problem at low altitudes, although if other factors have resulted in a condition where the available NSPH is close to the required NPSH, a drop in the barometer can result in failure of the pump to develop the desired capacity. At higher altitudes, of course, the lower atmospheric pressures may have a noticeable effect on the maximum capacity which can be pumped, and lifts then must be lowered, or larger suction hose used to compensate for the lowered pressure, in order to maintain the required NPSH. The table below gives the “standard barometric pressure at various altitudes:

Altitude, Ft. Above Sea Level	Atmospheric Pressure, PSIA
0	14.7
1,000	14.2
2,000	13.7
3,000	13.2
4,000	12.7
5,000	12.2
6,000	11.8
7,000	11.4
8,000	10.9
9,000	10.5
10,000	10.1

It can readily be seen, from the above, that high water temperatures, or low atmospheric pressure, will have exactly the same effect on maximum pump capacity as increasing the lift. A decrease in the available NPSH of 1 psi, which might result from either, is the same as would result if the lift were increased by 2.31 ft. Therefore, if a pump will draft a certain maximum capacity at a 14 ft lift at sea level with cold (50° F) water (presuming that adequate engine power is available), in order to get the same capacity with warm water and/or high altitudes, the lift would have to be lowered to the values shown below:

Altitude, Ft.	Water Temperature, ° F				
	90	100	110	120	130
3,000	9.3	8.8	8.0	7.0	5.8
5,000	7.0	6.4	5.7	4.7	3.5
7,000	5.2	4.6	3.9	2.9	1.7

Engine performance is dependent on the amount of air which can be drawn into the cylinders, as well as by the fuel-air ratio, fuel quality, and a host of other factors which we don’t need to discuss here. The fuel must be burned to develop the energy to make the engine run, and the amount of fuel which can be burned during each cycle is dependent on the amount of oxygen which is available. Anything which reduces the amount of oxygen available reduces the power developed in the cylinders. In a naturally aspirated (non super-charged) engine, the air must be drawn through the air cleaner, carburetor, and intake manifold by the pumping action of the pistons, similarly to the way water is drawn into the pump. While we don't have to worry much about NPSH and vapor pressure in considering this problem, we do definitely have to be concerned about the weight of the air drawn into the engine per cycle, rather than the volume. And, as air obeys the law as all good citizens do, it expands in direct proportion to a drop in absolute pressure, and also in direct proportion to an increase in absolute temperature. (Absolute temperature is the temperature above "absolute zero," and on the Fahrenheit scale is equal to the Fahrenheit temperature plus 459.7°; this is termed the "Rankine" temperature.

It is evident from the above that both atmospheric pressure and air temperature will affect the density of the air or, in other words, the weight of the volume of air drawn into the engine. Another climatic condition which affects this is the relative humidity--this is a measure of the water vapor content of the atmosphere, and obviously the higher the water vapor content, the lower the oxygen content. (Really, it is the "specific humidity," or the weight of the water vapor per pound of air which is important; but the "relative humidity," which is merely the proportion of the actual amount of water vapor to the maximum the air can hold at a given temperature, is easy to determine and can be used to calculate the effect on engine power.)

As the altitude increases, the atmospheric pressure decreases, as discussed above. The effect of the atmospheric pressure on engine power can be expressed simply: with constant temperature, the total power developed in the cylinders (indicated horsepower or IHP) will be decreased by the ratio of the absolute pressures; i.e., for every 100 hp developed at 14.7 psia (dry air), only 100 x 12.2/14.7, or 83 hp will be developed if the pressure is 12.2 psia (the normal atmospheric pressure at an altitude of 5000 ft). (The relative effect on brake horsepower, or the power delivered to the flywheel, will be greater than this as we shall see later.) A similar variation will occur at any single altitude if the atmospheric pressure varies due to changes in the climate. For instance, if the temperature stays constant, and assuming dry air, for every 100 hp developed at "standard" barometric pressure at sea level (14.7 psia), only 96-1/2 hp will be developed if the pressure drops 1/2 psi (about one inch of mercury).

Air temperature, if it varies widely, also can have a profound effect on engine performance. Engines are rated at a certain temperature- - commonly 85°F (545° Rankine). If the temperature is 100°F, the power developed in the cylinders of a gasoline (spark ignition) engine (IHP) will be less than at 85°F, by the ratio of √545/560, or approximately 99%[1]; if the temperature is 0° F, the power will be greater by the ratio √545/460, or 109%.

Relative humidity (RH) affects engine performance, as pointed out above, because the water vapor in the atmosphere takes the place of some air and, therefore, the higher the humidity the less oxygen will be made available to burn the fuel. The effect is minor compared to those of changes in atmospheric pressure and temperature- - normally the variation in power due to this factor is less than 1%. It is a significant factor only if the temperature and relative humidity are both quite high- - at 100°F, with a barometric pressure of 14.0 psi, for every 100 hp developed at 10% RH, only 96- 1/2 hp will be developed at 60% RH.

Now, how do these climatic variations really affect the power delivered at the flywheel and available to drive the pump? As stated above, pressure temperature, and humidity variations affect the total power developed in the cylinders (IHP). But some of this power is lost in overcoming friction within the engine (friction horsepower or FHP), and more is lost in driving accessories such as the fan, steering pump, alternator, etc. These losses will be about the same at any given speed, regardless of the developed engine power. For the purpose of this discussion we can assume that the FHP will be 20% of the IHP, and maximum power available at standard atmospheric conditions, as indicated by the net published curve (net BHP), will be 70% of the IHP. It follows, therefore, that the variation in maximum horsepower available due to non-standard atmospheric conditions will be greater, percentagewise, than the variation in IHP.

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[1] These variations are according to the SAE Test Code, and are based on test results which indicate that other influences than purely fundamental considerations affect that actual variations in power. While probably not completely accurate, they are sufficiently accurate for the purpose of this discussion.

We have seen above that in going from sea level to 5000 ft altitude with the temperature constant, we would reduce each 100 IHP to 83 IHP. Now, let's consider an engine which has a net BHP of 200 at standard conditions and a certain speed. The IHP would be about 286 hp, as we have assumed that the net BHP would be 70% of the IHP. Friction and accessory losses would be, therefore, 86 hp at this speed. At 5000 ft and the same temperature, the IHP would be only 286 x 83/100 or 237 hp. So the brake horsepower at 5000 ft would be 237 - 86, or 151 hp. Thus, the loss in brake horsepower due to the change in altitude would be from 200 hp to 151 hp, or 24-1/2%. This is 4.9%/1000 ft.[2]

Similarly, the effects of temperature and/or humidity will be greater, percentagewise, on the net power than on the gross hp or the IHP.

Diesel (compression ignition) engines are affected somewhat differently from gasoline (spark- ignition) engines by climatic factors, but if they are naturally-aspirated the results will be quite similar. Engines super- charged by positive- displacement blowers operating at speeds which have fixed ratio- to- engine speeds will be affected similarly. Turbo- - charged engines are a different case, as we shall see below.

To partially compensate for the effects of altitude, engines are sometimes made with special pistons, or special heads, which increase the compression ratio. Also, of course, carburetion is usually changed to suit on engines to be used regularly at high altitudes; this, however, merely acts to correct the air-fuel ratio to compensate for the lesser weight of air--it cannot overcome the problem of less available oxygen, but merely matches the fuel charge to the smaller air charge. Turbo-charged engines incorporate turbine-driven superchargers which increase the mass flow of air (total weight of air flowing per unit of time) at approximately the correct rate, as altitude is increased to compensate for the lesser density of the air. Some turbo-- charged engines will develop essentially the same power at 5000-6000 ft as at sea level.

CONCLUSION

We can sum up as follows:

Pump Capacity may be limited by

1. low atmospheric pressure, or
2. high water temperatures

Engine Power will be

1. lowered by lower than normal barometric pressure,
2. lowered by higher than normal air temperature,
3. lowered by higher than normal relative humidity, or
4. raised by colder than normal air temperature.

At High Altitudes

1. Pumps must be supplied by larger suction hose than normal, or used at low lifts, and
2. engines must be chosen with regard to their net power at the altitude where they will be used.

There is no practical way to test a pumper at low altitude. It is not practical to attempt to check power available at the higher altitude by imposing an extra load at the lower altitude. The performance of a new pumper should be checked at delivery, at the destination, by competent authorities, always keeping in mind that climatic conditions at that location can very widely from day-to-day, enough to result in significant differences in performance.

[2] If the gross power curve (no deductions for accessories) were used, the gross hp at sea level would be 286 x 0.080, or 229 hp. At 5000 ft it would be 237 - (286 - 229), or 237 - 180 hp. The loss due to altitude would be 229 - 180 or 49 hp, which is about 21.4%, or 4.28%/1000 ft.