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THE EQUATION $EP = NP + FL + APP + ELEV$ IS THE basic equation every pump operator needs to calculate when operating the fire pump. Today, many pump panels have flow meters that allow the pump operator to match the readout on the pump panel with the gallon-per-minute (gpm) flow of the selected nozzle. This is a disservice to the integrity of the pump operator. A knowledgeable operator needs to understand how a proper fire stream is developed and how each part is applied. Only with this knowledge can the pump operator go from being a knob puller who sets predetermined figures on a gauge to an efficient engineer capable of filling the hoselines with the proper amount of water not only to extinguish fires but also to keep crews safe on the fireground.

Each figure can be calculated using simple math. How the concepts are developed is explained below. The engine pressure is calculated by plugging numbers into each figure and adding or subtracting them.

- $EP =$ Engine Pressure
- $NP =$ Nozzle Pressure
- $FL =$ Friction Loss
- $Elev =$ Elevation Loss or Gain
- $App =$ Appliance Friction Loss

Some figures may be used more than once; others may not be used at all. If more than one size of hose is used, you will have to figure friction loss for each size. This also applies if multiple appliances are used or if hoselines are laid both up and down a hill. The pump operator needs to account for each of these figures each time a hoseline is pulled from the apparatus.

**NOZZLE PRESSURE**

To be called a fire stream, a hoseline needs to have a nozzle attached to its end. This nozzle gives the stream its shape, reach, and velocity. By definition, a fire stream is a stream of water after it leaves the nozzle until it reaches its final destination, which is usually the seat of the fire. As the streams are being produced, they are affected by the discharge pressure, nozzle design, and nozzle setting. A discharge pressure that is too strong not only will be very hard to handle but will also break up into smaller droplets, which aren’t as effective in extinguishing the fire. A discharge that is too weak may not be delivering enough gpm to overcome the British thermal units (Btus) being produced by the fire. An adequate stream also needs to have the reach to be able to hit the seat of the fire.

After the water leaves the nozzle, the stream is also affected by nature in the forms of gravity and wind. The stream needs to be strong enough to overcome these factors. There has to be enough reach so the firefighters don’t have to be in the absolute hottest environment. If the stream falls short of the fire, it cannot extinguish the fire. If the stream isn’t capable of overcoming the wind, it may not be possible to place the water on the seat of the fire, where it is needed.

**STANDARD PRESSURES**

The fire service uses three standard nozzle pressures. These standards are derived from years of trial and error and experience. The nozzle pressure can be adjusted upward to deliver more gpm flow or downward to make the line more maneuverable. Unfortunately, we can’t have both. If the nozzle pressure is increased, a few more gpm can be delivered, but the hoseline will become stiffer and harder to handle. There is even a point where the pressure becomes so great that the turbulence in the stream prevents the producing of a working fire stream. If the nozzle pressure is decreased, the hoseline will be easier to handle but at the expense of lower gpm. The standards give a good compromise for delivering the best of both worlds. To extinguish the fire while being able to maneuver the hoseline, the following nozzle pressures have been adopted:

- Smooth bore handline: 50 pounds per square inch (psi).
- Fog nozzle handline: 100 psi.
- Smooth bore master stream: 80 psi.
These standards give us a good basic starting point in figuring the overall engine pressure.

**SMOOTH BORE NOZZLES**

A smooth bore nozzle is simply a tube that narrows down to an opening with a specific inside diameter. As the water gets narrowed through the nozzle, it develops its smooth solid stream. In the late 1890s, John R. Freeman conducted experiments designed to define what a good solid stream is. He came up with four requirements that are still used today:

1. A stream that has not lost its continuity by breaking into showers or a spray.
2. A stream that shoots nine-tenths of the whole volume of water inside a 15-inch-diameter circle and three-fourths of its volume into a 10-inch-diameter circle at its break-over point.
3. A stream stiff enough to attain, under fair conditions, the named height or distance, even through a breeze.
4. A stream that, with no wind blowing, will enter a room through a window and strike the ceiling with enough force to splatter well.

These standards give a good foundation for building a good quality fire stream.

**DISCHARGE**

As we know, it is not the pressure of a stream that extinguishes a fire but the amount of water in gpm that cools a fire. The officer in charge of a fire needs to determine the amount of water needed to extinguish the fire and choose the appropriate hoseline and nozzle that will deliver the correct gpm. Large fires make for good news coverage, but in reality they happen because the firefighters were unable to place enough water at the seat of the fire to overcome the Btus being produced. The officer as well as the pump operator need to know the gpm flow from different nozzle tips to know how much fire each can extinguish. As a general rule, the maximum nozzle diameter should not exceed one-half of the size of the hose to which it is attached—for example, a 2½-inch handline should not have a smooth bore nozzle any larger than 1¼ inches. A 1¾-inch handline should have a nozzle tip no larger than 7⁄8 inch.

The amount of water discharging from a smooth bore is determined by the nozzle pressure and the inside diameter of the opening. The formula for determining the gpm flow from a smooth bore nozzle is as follows:

$$29.72D^2\sqrt{P}$$  \(D = \text{nozzle diameter}; \sqrt{P} = \text{square root of pressure}\)

For example, a one-inch smooth bore tip will have a discharge of 210 gpm: \(29.72 \times 1^2 \times 7.07 = 210 \text{ gpm}\).

**FOG NOZZLES**

Many fire departments have chosen to place combination fog nozzles on their apparatus. They feel that it is important to have the option of delivering a stream that can be adjusted from a straight stream to a wide fog pattern. Many officers and nozzle operators like having the flexibility a fog nozzle provides. This nozzle is also good for auto fires, other outside fires, and liquid petroleum fires.

Note that I did not say solid stream when referring to the pattern setting. At the narrowest pattern, a fog nozzle still produces a fog stream. It consists of tiny water droplets discharged in a uniform direction toward the fire. The small water droplets, if applied properly, will absorb the heat faster than a solid stream. This is because there is more surface area with all of the droplets compared with a solid stream. Another advantage of having tiny water droplets is that they quickly turn into steam. When a fire is in an enclosed space, a relatively small amount of fog stream can be shot into the area (the area is sealed tight), and the water will turn into steam smothering the fire. This is called the indirect attack method. Its advantage is that it uses relatively small amounts of water. This helps in preventing water damage to the structure. This method of attacking fire was first developed by Chief Lloyd Layman while he was in the U.S. Coast Guard. When water turns to steam, it expands. The amount of expansion is determined by the amount of heat in the room.

Note: The indirect attack is used only in enclosed spaces where there is no possibility of life in the room. The steam will burn and kill anyone inside the environment. If there is a possibility that someone is in the room, including firefighters, use a fog pattern in conjunction with proper ventilation. As the water is turned into steam, it will cool the burning material, but the steam has to be allowed to escape to the outside. A close-up fire attack must be coordinated with proper ventilation. Table 1 shows the amount of expansion at various temperatures.

**FRICITION LOSS**

In the fire service, friction loss is defined as the loss of energy in pressure whenever water runs through hoses, fittings, and appliances. As water runs through hose, it rubs...
against the lining of the hose, the couplings, and even itself. Each time this happens, friction causes the water to slow down. Pump operators need to compensate for this loss. As far as pump operators are concerned, there are two ways this can happen. As the water flows through the hoses and appliances, it rubs against the lining of the hose and appliances, causing friction. It also flows over couplings and around bends in the hose, causing friction. Picture a single drop of water inside the hose. As it flows along, it contacts the lining, a coupling, or a bend in the hose. As it makes this contact, it changes direction even slightly and stops flowing in a nice straight line. This will slow down the forward velocity of the droplet. This is the simplest explanation of friction loss. Every time the water changes direction for any reason, friction is created.

Friction is also caused by the water itself. As a liquid flows past itself, it creates friction with the layers next to it. As each layer comes in contact with another layer, it moves and changes direction. This causes the velocity to slow down. A good example of this can be seen when pouring very thick syrup down a gentle slope. If you watch the front end of the syrup, it will look as if it is rolling down the slope. Each layer seems to grab the layer next to it and pulls it along. Water does the same thing. As it flows through the hose, it rubs and pulls and moves in directions other than the straight line we want.

A simple way of demonstrating this principle is to turn on your garden hose. Without connecting a nozzle to the end, place the hose in a straight line. The water coming out the end runs in a nice smooth stream. Immediately at the end of the hose, the water has a nice, solid, cylindrical shape. Now slightly kink the hose about 12 to 18 inches behind the discharge opening. You now see not only that the stream has lost its forward velocity but also that the shape of the stream isn’t nearly as uniform as before. This is a very simplified version of what happens inside a fire hose.

Friction loss in fire hose is governed by the following rules:

1. **Friction loss varies with the quality of the hose.** The thickness of the inner lining, the age of the hose, and the weave of the jacket all affect the quality of the hose. Even with the advancement in the quality of the inner lining of the hose, some friction still exists. It is impossible to have a perfectly smooth inner lining. Every little imperfection in the lining will create friction.

2. **Friction loss varies directly with the length of the hose.** Friction loss is calculated in 100-foot lengths; the total friction loss is figured when all lengths are added together. For example, if the friction loss in one length of 1¾-inch hose is 15 psi, then if four 100-foot lengths are added together, the total friction loss would be 60 psi.

3. **Friction loss varies with the square of the velocity.** If the velocity is doubled, the friction loss is quadrupled. If the velocity is quadrupled, the friction loss will be increased 16 times.

4. **For a given flow, the friction loss varies inversely as the fifth power of the diameter of the hose.** This is the most important thing to understand when limiting the effects of friction loss. This rule shows why it is important to increase the diameter of the hose when trying to keep friction loss to a minimum. While keeping the flow the same, as the hose size is doubled, the friction loss is only \((\frac{1}{2})^5\) or \(\frac{1}{32}\) times the friction loss in the smaller hose. This is the reason many fire departments switched from 1½-inch hose to 1¾-inch hose. This is illustrated as follows:

\[
1.75^5 + 1.5^5 = 1.167^5 = 2.16
\]

This shows that the friction loss in 1¾-inch hose is half of that for a 1½-inch hose. A 1¼-inch hose isn’t any more difficult to handle than the smaller 1½-inch hose and has much less friction loss, but it can deliver a larger volume of water at the same pressure.

5. **For a given velocity, friction loss is independent of the pressure.** The amount of friction loss in a hose depends on the amount of water flowing through the hose and the velocity at which it is moving. If the hoseline is laid up a hill, the pump will need to overcome the back pressure created by the elevation, but the friction loss would remain the same. If the friction loss in 100 feet of 2½-inch hose is 15 psi, the pressure in the hoselay would decrease by 15 psi for every 100-foot length connected, but the pump discharge pressure will need to be increased to compensate for the elevation loss.

### The Friction Loss Formula

As stated before, there are many factors that affect how much friction loss there might be in a given length of hose. It is nearly impossible to tell the condition of the lining, for example. The only true way to figure the amount of friction loss is to connect pressure gauges to each end of the hoseline, place the hoses in straight lines and on level ground, and subtract the difference. It is important to keep the hose and equipment in good working condition at all times to eliminate as much of the friction-causing problems as possible.

For many years, certain formulas have been used to get a fairly accurate measurement of the friction loss. These formulas are not perfect, but they are adequate for the fire service.

#### Underwriters’ Formula

The most widely used formulas for determining friction loss in a single 2¼-inch hoseline are the following:

\[
FL = 2Q^2 + Q \quad \text{and} \quad FL = 2Q^2 + \frac{1}{5}Q
\]

These formulas are called the “Underwriters’ formulas.” The first is used when the gpm flow is 100 gpm or higher. The second formula is used for flows lower than 100 gpm.
In calculating these formulas, start by knowing how many gpm of flow you have based on the nozzle tip size. Divide the gpm figure by 100 to give you “Q.”

\[
Q = \text{gpm} / 100 \quad \text{Example: } Q = 400 \text{ gpm} / 100 = 4
\]

When calculating friction loss for hose sizes other than 2½ inch, you must use a conversion factor. You calculate the factor by using friction loss rule #4, which states: “If the flow stays the same, the friction loss varies inversely as the fifth power of the diameter of the hose.” Table 2 shows the conversion factor for different hose sizes.

Multiply or divide the formula by the conversion factor to get the correct friction loss.

**COEFFICIENT FORMULA**

Another formula used by some fire departments is “CQ²L.” Some believe this formula is easier to use, but the operator needs to remember the coefficient for each hose size.

\[
C = \text{Coefficient} \\
Q = \text{Gpm} / 100 \\
L = \text{Length in 100 feet}
\]

A coefficient is a number used for a specific hose size. Table 3 shows various hose sizes and their coefficients.

When comparing calculations of each of the two formulas, you will notice the answers are slightly different. Which formula is correct? The answer is “both.” There is no right or wrong formula; fire departments use either formula. As stated before, there are too many factors involved to accurately calculate a friction loss. The only way to accurately figure the friction loss in any length of hose is to place pressure gauges on each end of the line and subtract the difference. The important thing is to work with both formulas and see which works best for you.

**COMBINATION LAYOUT**

Until now we have discussed only single hoseline layouts; single lines are easy to figure. You only need to figure one friction loss and apply it to the overall formula. But what happens when there is a combination layout?

A combination layout consists of multiple hoselines that combine into one or one hoseline that divides into more than one line. The most common combination layout consists of multiple lines that combine into one.

These layouts are used any time more water is needed at the nozzle than can be easily delivered through any one hose-line. For example, when very long hose stretches are needed, there would be too much friction loss in one single hoseline, so it is divided among two or more lines and then connected with a siamese into the attack line. Another situation is supplying a standpipe or a sprinkler connection on a building. Two or more hoselines are connected at the building and then one internal pipe carries the water to where it is needed.

The most efficient way of calculating this type of layout is to break the layout down into separate parts.

1. It is best to separate the attack line first. We know that a one-inch tip flows 210 gpm. Using that, we can figure the friction loss for this section: \(2Q^2 + Q \times L = 9.25\).

2. Next, figure the friction loss in the two lines supplying the attack line. Divide the total gpm (210) by the number of hoselines (2), and figure the friction loss for one of the lines. The other line will be the same. Each hoseline carries half of the total flow: \(2(1.05^2) + 1.05 \times L = 9.25\). Don’t add 9.25 twice. You need to figure and add it only once. Even if there are five supply lines, figure the friction loss for one line, and add it only once.

*Note:* If the hoselines that are going to be split are two different lengths, average the two. If at all possible, it would be better to change the lines so they are the same length. It is also best if the same size hoselines are used. This makes the calculations reasonably easy to figure.

**OTHER APPLICATIONS USING THE SIAMSE**

The siamese is used to convert multiple hoselines into one line when supplying a standpipe or a sprinkler connection. Multiple lines connect to the building and supply attack lines or sprinkler heads. The siamese is used also when an engine needs to supply a ladderpipe on an aerial ladder. The mistake many people make is not to divide the gpm among however many supply lines there are. If the total flow is not divided among the separate lines, the calculations will be way too high.

Wyed lines take special considerations. The same principle applies when a supply line is split into two attack lines. Each section needs to be figured separately, but it is extremely important that each attack line be the same as the other. Each needs to be the same diameter hose and the same length, and each needs to flow the same gpm from the nozzle. If the attack lines are different, the friction loss will be different in each line, and it will be impossible to correct overall friction loss.

*Example:* The friction loss for the supply line is 30 psi. One attack line is 200 feet of 1¾-inch hose with a 200-gpm fog nozzle. The friction loss for this hoseline is 120 psi.

The second attack line is 200 feet of 1¾-inch hose with a 100-gpm fog nozzle. The friction loss for this hoseline is 36 psi.

If the 200-gpm nozzle is supplied properly, the total friction loss would be calculated as follows:

\[
\text{Total Friction Loss} = 0.12 \times 200 + 0.036 \times 200 = 38.4 \text{ psi}
\]
loss would be 150 psi. There is no possible way of supplying the second line with the proper 66 psi. It is not physically possible to pump two separate pressures through one hoseline.

Another situation where more than one friction loss needs to be figured is when very long hoselays are needed. For example, an engine is pumping while at a hydrant, and the fire is a long distance away. The best thing to do is to pump through larger-diameter hose up to the fireground and then have a shorter attack line that is smaller in diameter and easier to maneuver.

**Question:** What is the total friction loss in 700 feet of three-inch hose reduced to 200 feet of 1¾-inch attack line with a one-inch straight tip?

**Answer:** Figure the attack line first:

\[2 \times 2.1^2 + 2.1 \times 2 \times 6\]
\[65.52 \times 2 \text{ (length)}\]
\[= 131.04 \text{ psi}\]

Next, figure the three-inch hose:

\[2 \times 2.1^2 + 2.1 \times 6\]
\[4.37 \times 7 \text{ (length)}\]
\[= 30.59 \text{ psi}\]

Finally, add the two together: \[131.04 + 30.59 = 161.63 \text{ psi.}\]

As you can see, if the entire hoseline were 900 feet of 1¾-inch hose, the friction loss would be 589.68 psi. A pressure this high would be very hard on the pumps and certainly would burst the hose. That is the reason it is so important to pump through a larger-diameter hoseline for all the distance except for the attack line.

When you are on the scene of a two-alarm fire, the pump operator doesn’t have time to figure friction loss for every hoseline. Most fire departments calculate the friction loss for the hoses and nozzles they carry and write them on what is called a “pump chart.” Most charts list the nozzles on the apparatus, their gpm, and the friction loss. The operator simply needs to look at the chart and start adding the figures. This makes it much easier and quicker on the fireground where time is critical.

Friction loss happens every time water flows through hoses, pipes, or appliances. Every time a hoseline is pulled, the pump operator needs to account for it to give the nozzleman the proper amount of water to extinguish the fire. It is the pump operator’s primary responsibility to get the calculations right and supply the hoseline with the proper pressure and flow rate. Improper calculations can create dangerous situations for the crews inside the fire area. Too low of a pressure will create a situation where there is not enough water to extinguish the fire; too high a pressure can possibly injure the fire crews inside the building. When calculating friction loss, memorize whichever formula your department uses as well as the friction loss rules and how they are applied.

**APPLIANCE FRICTION LOSS**

In the above section, appliances such as wyes, siameses, and reducers were never figured into the friction loss calculations. They are so special that they get their own calculation in the overall equation. Appliances are devices designed to work in conjunction with hoses to help deliver the water. They are designed to be placed in the middle or at the end of a hose layout to deliver the water. Even fire department connections for standpipes are considered appliances. Ladderpipes on aerial trucks are considered appliances. Appliances can be used to combine or divide hoselines or to help deliver the water to where it needs to go.

Every water appliance used in the fire service, from a simple wye to a ladderpipe, has friction loss. The manufacturers of these appliances work hard to keep the amount of friction loss to a minimum but, as noted before, each time the water moves or changes direction, friction is created. Each engine company should keep track of what appliances are on the rig and who makes them. If manuals are not available, go to the Web site or contact the company and learn as much about each one as possible. There are lists and charts diagramming the friction loss for given flows.

Just as with hoselines, every time water changes direction, more friction loss is created. As the water is split, combined, or moves through the appliance, it will change direction, which causes friction loss. The same friction loss rules apply. As the inside diameter increases, the friction loss decreases. Just as the velocity increases, so does the friction loss.

Many fire departments such as the Denver (CO) Fire Department give set

---

**Table 4. Friction Loss and Appliances (Denver Fire Department)**

<table>
<thead>
<tr>
<th>Appliance</th>
<th>Friction Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Siamese</td>
<td>5 psi</td>
</tr>
<tr>
<td>Wye</td>
<td>5 psi</td>
</tr>
<tr>
<td>Bresnan Distributor (1¾-inch)</td>
<td>3 psi</td>
</tr>
<tr>
<td>Bresnan Distributor (2½-inch)</td>
<td>5 psi</td>
</tr>
<tr>
<td>Multiversal</td>
<td>10 psi</td>
</tr>
<tr>
<td>Deck Gun</td>
<td>10 psi</td>
</tr>
<tr>
<td>Ladderpipe</td>
<td>15 psi</td>
</tr>
<tr>
<td>Standpipe System</td>
<td>25 psi</td>
</tr>
</tbody>
</table>
values for each appliance. These friction loss values are averages based on the flows usually associated with each appliance. When pumping at a fire, these figures are accurate enough.

Table 4 contains the friction loss the Denver Fire Department assigns to appliances.

These are just some of the appliances in use today. Inventory your apparatus, and make sure that each piece of equipment is accounted for and the friction loss for each one is known. Check with the manufacturer, if necessary, to determine the friction loss for each appliance.

**ELEVATION**

Elevation is the last calculation we need to make to finish the equation. In firefighting terms, elevation is pressure created by gravity. Unless the hoselines are laid on perfectly flat ground, you need to adjust for elevation. Many times, the elevation change is minimal, but the pump operator needs to be aware at all times. In many municipalities, a house will sit higher than the street. Take a look at the driveway and note if there is a slope to it. This pressure needs to be calculated when moving both up and down in elevation. At times, the hoseline is pulled up a hill and then down the other side. Other times, the hoselines are laid on flat ground into standpipe connections, but the attack line is being used on an upper floor of the building. Every time water is moved higher or lower than the pump, you need to make adjustments.

The downward pressure of a liquid is directly proportional to its depth. A one-inch by one-inch column of water standing one foot tall will have a pressure at its base of 0.434 pounds. The pressure will increase by 0.434 pound for every foot added to the height. The pump operator needs to adjust for this pressure.

**HEAD PRESSURE**

“Head” refers to the vertical distance from the top of the water to where it is being used. The amount of pressure created by gravity depends on the height of the level of the water in comparison to where it is being used. For example, a column of water 50 feet tall will create a pressure of 21.7 pounds at its base. The opposite is also true. If 21.7 pounds of pressure are applied to the base of the column, the water will rise 50 feet.

**Determining the Pressure When the Head Is Known**

Before mechanical pumps were used on water distribution systems, gravity was used to increase pressure. Water tanks were placed on buildings and towers to deliver water to sprinkler systems and hydrants. These tanks were placed at varying heights according to how much pressure was needed. A reservoir high in the mountains can deliver the pressures needed to supply a city below. Cities such as Denver are fortunate to have tall mountains full of reservoirs close by. The reservoirs fill up with water as the snow melts, and the cities below use what they need throughout the year. It is all gravity fed, allowing nature to take care of the cities below. Even though the reservoir may be miles away, the only thing that matters is the vertical distance between the reservoirs and where the water is being used. What matters is how much higher the reservoir is than where the water is being used. A water tank raised above the ground can supply a hydrant at ground level. The height of the water level in the tank will determine the pressure found at the hydrant. The formula for determining pressure when head is known is pressure (P) = 0.434 × head (H).

**Question:** The surface of the water in a gravity tank is 134 feet above a hydrant. What will be the static pressure on the hydrant created by head?

**Answer:**

\[ P = 0.434H \]

\[ P = (0.434)(134) \]

\[ P = 58.16 \text{ psi} \]

**Overcoming Head Pressure**

The examples have shown only head pressure moving toward the ground from an elevated height. Head also applies in elevation. When hoselines are placed up a hill or into a building, a pumper is needed to overcome the pressure caused by head. Every time a pump operator pumps into a standpipe connection on a building, he needs to make an elevation calculation. In many jurisdictions, this happens many times a day. The same formula applies; only the pump operator needs to add this pressure to the formula. If a nozzle operator is 40 feet up a hill, the pump operator needs to add pressure to overcome the head pressure working against the pump. This pressure is called “back pressure.”

\[ P = H \times 0.434 \]

\[ P = 40 \times 0.434 = 17.36 \text{ psi} \]

**Question:** What would be the back pressure when pumping up a 35-foot hill?

**Answer:**

\[ P = H \times 0.434 \]

\[ P = 35 \times 0.434 = 15.19 \text{ psi} \]

The pump operator needs to add this pressure to the calculation. If the nozzle were 40 feet down a hill, the pump operator would need to subtract the pressure. This pressure is called “forward pressure.”

\[ P = H \times 0.434 \]

\[ P = 40 \times 0.434 = -17.36 \text{ psi} \]

Sometimes the lines aren’t laid so easily up or down a hill. Many times, the hose travels down a hill and back up another hill. The pump operator simply needs to find the difference. For example, if the hoseline is pulled up a 30-foot hill then down the other side a total of 20 feet, the operator needs to adjust for a rise of 10 feet.

\[ P = H \times 0.434 \]

\[ P = (30 - 20) \times 0.434 \]

\[ P = 10 \times 0.434 \]

\[ P = 4.34 \text{ psi} \]

In this case, 4.34 psi needs to be added to the calculation because the final height is above the level of the pump. In mountain areas, the pump operator finds this a common occurrence. Most of the time, trying to figure the overall elevation change becomes a guessing game. The easiest way is to figure a starting point and an ending point and calculate the difference. One of
the first fires I pumped at happened to be a situation like this. When I looked, the terrain dropped down to the entrance of the building, but the fire was on the third floor. As I looked across, it became clear that the fire was on the same plane I was on. This made for an elevation change of zero. So even though there were two elevation changes, the end result turned out to be zero.

The same formula applies when pumping into a building. The only difference is that we don't account for the height of the first floor because the fire department connection is usually about the same distance from the ground as the standpipe connection is from the fire floor. For example, a fire is on the seventh floor of a building in which each floor is 10 feet tall. We need to account for only six floors or 60 feet.

\[
P = H \times 0.434
\]

**Question:** What is the elevation pressure when pumping into a 35-story high-rise building that has a fire on the 27th floor? Assume each floor is 10 feet tall.

**Answer:**

\[
P = 60 \times 0.434
\]

\[
= 26.04 \text{ psi}
\]

**Question:** A fire is on the 14th floor of an office building. The pumper sits on a hill 30 feet above the fire department connection. What is the head, and what is the pressure because of elevation? Do we need to add or subtract the pressure from the calculation? Assume 10 feet per floor.

**Answer:** Up 130 feet minus 30 feet down = 100 feet total elevation change.

Elev = 130 – 30 = 100

Back Pressure (BP) = 100 * 0.434 = 43.4 psi

We need to add this pressure because the nozzle is above the level of the pump.

**PUTTING IT ALL TOGETHER**

Now that each part of the formula has been explained, you can put it all together. The easiest way to start is to write down the formula. Some people find it easier to draw a diagram of the hose layout to help visualize each part of the problem.

Remember that each part may be used more than once. There may be different sizes of hose or multiple appliances. Even if one or more parts of the formula are not used, it is always a good idea to write down the abbreviation anyway. All that is needed is to place a zero in its place. Many people find that starting with the nozzle and working backward is the best way to keep everything straight. Follow the water backward, and fill in the numbers in each spot.

In master stream operations, which use large volumes of water, every part of the formula is used. Generally, master streams are used when the volume of flow is higher than 350 gpm. Monitors, deck guns, elevated platforms, and ladderpipes are considered master streams. Even though large volumes of water are used, the same hydraulic principles apply. The tricky part is to recognize and break down each part that needs to be figured.

**Question:** Two 2½-inch hoselines, each 400 feet long, are laid to a monitor that is 30 feet above the pumper. The monitor has a 1½-inch smooth bore tip. What is the pump discharge pressure?

**Answer:**

\[
NP + FL + APP + ELEV
\]

NP = 80 (Master Stream)

\[
FL = 2Q^2+Q
\]

\[
FL = 2(3)^2+3
\]

\[
FL = 21/100 \text{ ft}
\]

\[
FL = 84
\]

APP = 10

ELEV = 30 \times 0.434

ELEV = 13

\[
80 + 84 + 10 + 13 = 187 \text{ psi}
\]

**Question:** You are supplying a ladderpipe that has a 1¾-inch nozzle and is elevated 80 feet. You supply the ladderpipe with two 2½-inch hoselines that are 200 feet long. (Hint: 100 feet of three-inch hose is laid up the ladder.)

**Answer:**

\[
NP + FL (2½”) + FL (3”) + APP + ELEV
\]

NP = 80

\[
FL (2½”) = 2Q^2+Q
\]

\[
FL (2½”) = 2(4.1)^2+4.1
\]

\[
FL = 2 \times 16.81 + 4.1
\]

\[
FL = 37.72 (38) \times 2 = 76
\]

\[
FL (3”) = CO^L
\]

\[
FL = .80 \times 8.14^2 \times 1
\]

\[
FL = 53
\]

APP = 20 (ladderpipe + siamese)

ELEV = 80 \times 0.434

ELEV = 34.72

\[
80 + 76 + 53 + 20 + 34.72 = 263.72 \text{ psi}
\]

That's it! That is the formula every pump operator needs to calculate each time a hoseline is laid. For new operators and even old timers who don’t practice every day, it is good to write the formula down each time a hoseline is pulled and plug in the numbers. If a number is written down for each value, the problem becomes a simple addition and subtraction problem. Sometimes more than one figure needs to be put in for each part—for example, there might be two or more friction loss figures. If the formula is written out, it is easier not to forget a calculation. Many of these calculations can be figured out ahead of time, written on a pump chart, and placed on the apparatus near the pump panel. The most important thing is to practice so there won't be any problems when you are needed at a fire.

**ENDNOTES**

1. John R. Freeman (1855-1932) was a civil engineer who was actively involved in fire protection and reducing the insurance costs of fire. His papers “Experiments Relating to the Hydraulics of Fire Streams” and “The Nozzle as an Accurate Water Meter” won awards from the American Society of Civil Engineers. His full biography is available on the Web at the Boston Society of Civil Engineers Section, www.bsces.org/index.cfm/page/Biography/pid/10709.


**PAUL SPURGEON** is a 20-year veteran of the Denver (CO) Fire Department. Promoted to engineer in 1998, he was assigned to Engine 7 in northwest Denver. He has earned an AAS degree in fire science and technology from Red Rocks Community College. He has authored Fire Service Hydraulics and Pump Operations (Fire Engineering).
Every Pump Operator’s Basic Equation

1) What is the basic equation used to calculate fire streams?
   a. EP=nP+FL+HP+ELEV
   b. EP=nP+FL+APP+ELEV
   c. EP=HP+nP+FL+ELEV+APP
   d. EP=FL+NP+ELEV+APP+Fog/Smoothbore

2) All figures used to calculate engine pressure must be used to develop a proper fire stream
   a. True
   b. False

3) If more than one size of hose is used, you must:
   a. Figure friction loss for each size
   b. Figure friction loss for only one size
   c. Figure friction loss for the longest hoseline
   d. Figure friction loss for the largest size only

4) To be called a fire stream, a hoseline needs to have a nozzle attached to its end
   a. True
   b. False

5) A discharge that is too weak:
   a. May still provide enough water
   b. May cause pump cavitation
   c. May not be delivering enough water to overcome the British Thermal Units (BTUs) being produced by the fire
   d. May require smaller diameter hose

6) After water leaves the nozzle, the stream is also affected by:
   a. Gravity and wind
   b. Air and velocity
   c. Elevation and gravity
   d. Gravity and velocity

7) The fire service uses three standard nozzle pressures for smoothbore handlines, fog nozzle handlines and smoothbore master streams. These pressures are:
   a. 50psi, 150psi and 75 psi, respectively
   b. 100psi, 80psi and 50 psi, respectively
   c. 50psi, 100psi and 80 psi, respectively
   d. All operate at 50 psi

8) A _______ is simply a tube that narrows down to an opening with a specific inside diameter
   a. Fog nozzle
   b. Combination nozzle
   c. Distributor nozzle
   d. Smoothbore nozzle

9) It is not the pressure of a stream that extinguishes a fire, but the amount of water in gpm that cools a fire
   a. True
   b. False

10) As a general rule, the maximum nozzle diameter should not exceed _______ of the size of the hose to which it is attached
    a. Twice
    b. Three times
    c. One-half
    d. Three-quarters

11) An advantage of fog nozzles’ ability to produce tiny water droplets is:
    a. Will absorb the heat faster than a solid stream
    b. Apply droplets to more areas of the room
    c. Assists with protecting firefighters from flashover
    d. There is no advantage to tiny water droplets

12) Which attach method has the advantage of using relatively small amounts of water?
    a. Combination attack
    b. Indirect attack
    c. Transitional attack
    d. Direct attack

13) The indirect attack is used only in enclosed spaces where there is no possibility of life in the room
    a. True
    b. False

14) What is defined as the loss of energy in pressure whenever water runs though hose, fittings and appliances?
    a. Head pressure
    b. Static pressure
    c. Friction loss
    d. Elevation loss
Every Pump Operator’s Basic Equation

15) What are the two ways water flows through hoses?
   a. Laminar and metric flow
   b. Laminar and turbulent
   c. Turbulent and parallel
   d. Parallel and laminar

16) In _______ flow, the water flows in parallel lines with the flow at the center moving at a greater velocity than at the edges, and decreases the further out towards the edges of the hose
   a. Turbulent
   b. Parallel
   c. Metric
   d. Laminar

17) As water contacts the edges of the hose lining, coupling or a bend, it causes
   a. Friction
   b. Laminar flow
   c. Rub turbulence
   d. Loss of water

18) Friction loss is governed by which of the following rules:
   a. Friction loss varies with the quality of the hose
   b. Friction loss varies directly with the length of the hose
   c. Friction loss varies with the square of the velocity
   d. All of the above

19) What are two friction loss formulas commonly used by fire departments?
   a. Underwriter’s Formula and National Fire Academy Formula (NFA)
   b. Underwriter’s Formula and Combination Formula
   c. Underwriter’s Formula and Coefficient Formula
   d. Coefficient Formula and NFA Formula

20) Water pressure will increase by .434 pound-per-foot increase in elevation which is why pump operators must adjust for this pressure
   a. True
   b. False
Every Pump Operator’s Basic Equation

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