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# Friction Loss in Wildland Hose Lays

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***Tech Tip Highlights***

- All firefighters should understand the fundamentals of friction loss and be able to use a friction-loss calculator.
- Friction loss can be reduced by increasing the hose size (diameter) or by decreasing the flow rate.
- Friction loss in appliances should be ignored when estimating friction loss in a hose lay.
- Friction loss in a hose lay is complex. This Tech Tip provides a simplified method, based on sound engineering principles, which will give a good estimate of friction loss in a hose lay.

## Introduction

Wildland fire engine operators should understand friction loss fundamentals and be able to determine a reasonable estimate of friction loss in order to set pump discharge pressure (PDP) on a wildland fire engine correctly.

Friction loss in a hose lay is complex. However, reasonable estimates, based on engineering principles, can be determined easily. This Tech Tip introduces methods for determining friction loss, discusses friction loss of appliances, and provides techniques for reducing friction loss. Additionally, this Tech Tip provides the following appendix information:

- Rules of thumb for hydraulics, appendix A.
- Technical information on friction loss, appendix B.
- The calculation method for determining friction loss, appendix C.

## Discussion

Friction is the resistance that results as water moves along the inside walls of fire hose and the turbulence within the water, both which produce a loss of energy (loss of pressure), measured in pounds per square inch (psi). The amount of friction loss depends on the volume of water moving through the hose, the hose size (diameter) and length, and the internal roughness of the hose.

Head (the pressure increase or decrease as a result of a change in elevation) does not affect friction loss. Friction loss is the same, whether the hose is laid uphill or downhill.

## Determining Friction Loss

To estimate friction loss for a wildland hose lay, two generally accepted methods can be used – a friction-loss calculator or friction-loss charts/tables. Based on their durability, calculators are better suited for field use. Engine operators should be familiar with both. Friction loss can also be calculated using the information provided in appendix C.

***Friction-Loss Calculators:***

Friction-loss calculators can be purchased from manufacturers of water-handling equipment, and also are available through National Interagency Support Caches (NFES 0897). A typical friction-loss calculator is shown in figure 1. The calculators have a scale to determine nozzle flow rates (gal/min*) at different nozzle pressures, and have another scale to provide friction loss values per 100 feet of hose for a given flow rate and hose diameter.

Friction loss is estimated in two basic steps: flow rate is established first, and then friction loss is determined.

Flow rate: For straight-stream tips, align 50 psi nozzle pressure with the arrow on the “nozzle discharge” portion of the calculator and read the flow rate (gal/min) corresponding to the applicable tip size. Combination (fog) nozzles are rated at a flow rate (e.g., 60 gal/min at 100 psi), so the discharge does not need to be determined. To reiterate, the “nozzle discharge” portion of a friction-loss calculator is only used for straight stream tips and is not needed for combination (fog) nozzles.

Friction loss: For either nozzle type, adjust the “friction-loss” portion of the calculator to the flow rate, and read the friction-loss value per 100 feet of hose for the desired diameter. Multiply the friction-loss by the number of 100 feet hose lengths to determine the total friction loss for a particular section of hose.

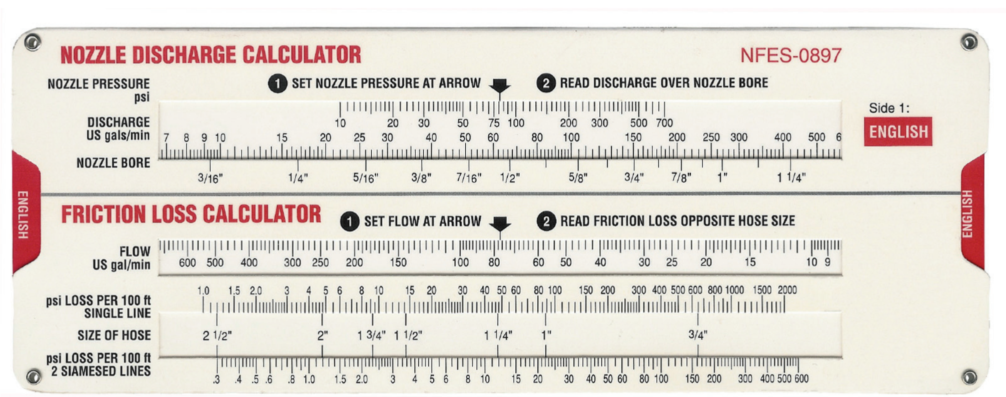


Figure 1—Commercial friction-loss calculator.

***Friction-Loss Tables:***

Friction-loss values (per 100 feet of hose) can also be read directly from tables. Table 1 provides values for straight-stream tips, and table 2 provides values for combination (fog) nozzles. Again, for either nozzle type, the friction loss (for 100 feet of hose) is multiplied by the number of 100-foot hose lengths to determine the total friction loss for a particular section of hose.

> Note: The values for tables 1 and 2 were determined by using the formula and “practical use” coefficients in appendix C. The “practical use” coefficients are based on testing performed by the San Dimas Technology and Development Center (SDTDC). Most new commercial friction-loss calculators are based on the “published values” shown in appendix C. This means that tables 1 and 2 will not always agree with the values obtained from new friction-loss calculators. Interestingly, many older friction-loss calculators correlate closely with tables 1 and 2 (and--correspondingly--with the practical use coefficients in appendix C).

*Editor’s note: Although “gpm” is used universally by firefighters to abbreviate flow rate in gallons per minute, the government style manual requires the use of “gal/min” in publications.

Table 1—Friction loss per 100 feet for straight-stream tips with 50-psi nozzle pressure.

| STRAIGHT STREAM TIPS | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Tip Orifice Size (in) | 1/8 | 3/16 | 1/4 | 5/16 | 3/8 | 1/2 |
| | Flow (gal/min) | 3 | 7 | 13 | 21 | 30 | 53 |
| | **HOSE DIAMETER (inch)** | **FRICTION LOSS** | | | | | |
| Friction Loss per 100' (psi) | 5/8 | 2 | 11 | 34 | 84 | 174 | 551 |
| | 3/4 | 1 | 6 | 19 | 46 | 96 | 303 |
| | 1 | 0 | 1 | 4 | 11 | 22 | 69 |
| | 1-1/2 | 0 | 0 | 1 | 1 | 3 | 10 |
| | 1-3/4 | 0 | 0 | 0 | 1 | 1 | 4 |
| | 2-1/2 | 0 | 0 | 0 | 0 | 0 | 1 |

Table 2—Friction loss per 100 feet for combination nozzles with 100-psi nozzle pressure.

| COMBINATION (FOG) NOZZLES | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Flow (gal/min) | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
| | **HOSE DIAMETER (inch)** | **FRICTION LOSS** | | | | | | | | | |
| Friction Loss per 100' (psi) | 5/8 | 20 | 80 | 180 | 320 | 500 | 720 | 980 | 1,280 | 1,620 | 2,000 |
| | 3/4 | 11 | 44 | 99 | 176 | 275 | 396 | 539 | 704 | 891 | 1,100 |
| | 1 | 3 | 10 | 23 | 40 | 63 | 90 | 123 | 160 | 203 | 250 |
| | 1-1/2 | 0 | 1 | 3 | 6 | 9 | 13 | 17 | 22 | 28 | 35 |
| | 1-3/4 | 0 | 1 | 1 | 2 | 4 | 5 | 7 | 9 | 11 | 14 |
| | 2-1/2 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 2 | 2 |

### Friction loss in appliances

Historically, the accepted method for calculating pump discharge pressure has been:

**PDP = NP +/- H + FL + A**

Where:

**PDP** = Pump discharge pressure, or engine pressure (EP)

**NP** = Nozzle pressure

**H** = Head (positive for an uphill hose lay, negative for a downhill hose lay)

**FL =** Friction loss

**A** = Appliances (5 psi per appliance)

Extensive testing by SDTDC has shown that the actual friction loss for appliances such as hose-line tees and gated-wye valves is less than 1.0 psi. The pressure losses in 1-½ inch appliances at 50 gal/min were as follows:

| | |
|---|---|
| Wye valve | 0.46 psi |
| Hose line tee | 0.05 psi |
| Hose line tee w/ valve | 0.77 psi |

Based on these results, ignoring friction loss in appliances is more accurate than arbitrarily assigning a 5 psi pressure loss to each appliance in a hose lay.

**Appliance friction loss should be ignored when determining friction loss in a wildland hose lay**. This is true for any hose-lay length, including very long hose lays with thousands of feet of hose and numerous tees or wye valves, because appliance friction loss is a very small percentage of the total friction loss in a hose lay. The suggested method for calculating pump-discharge pressure is:

**PDP = NP +/- H + FL**

### Techniques for Reducing Friction Loss

***Increase the hose diameter***

Increasing the hose diameter reduces friction loss because the water is flowing through a larger area. For example, a 1-inch hose has about seven times the friction loss of a 1½-inch hose. Referring to table 2, the friction loss for 1-inch hose is 63 psi at 50 gal/min, and the friction loss for 1½-inch hose is 9 psi at 50 gal/min (63/9 = 7 , friction loss decreased by a factor of seven).

***Lay a parallel hose line***

With all other factors remaining constant, two parallel lines of hose will have one-fourth the friction loss of a single line of the same diameter and length carrying the same quantity of water. For example, referring to table 2 for 1-inch hose, the friction loss at 40 gal/min is 40 psi, and the friction loss at 20 gal/min (representing the same amount of water flowing parallel in two hoses instead of one) is 10 psi (one-fourth the friction loss).

***Reduce the size of the nozzle tip and maintain the same nozzle pressure***

Reducing the tip size and maintaining nozzle pressure reduces the discharge flow. Reducing the tip size (diameter) by one-half decreases the water flow rate by 4 times. For example, referring to table 1, the flow through a 1/2-inch tip is 53 gal/min and the flow through a 1/4-inch tip is 13 gal/min, a decrease of approximately 4 times. Caution: A decreased flow may not be adequate for the desired suppression task.

***Reduce nozzle pressure***

If the nozzle pressure is reduced, the discharge flow will be reduced thereby reducing friction loss. Caution – Once again, the amount of water that is being discharged from the nozzle will be reduced. The “rule of 3/4” can be used in estimating nozzle discharge when pressure is reduced – halve the pressure and the flow is reduced to about three-fourths (the actual reduction is about 71 percent). For example, referring to a friction-loss calculator such as the one shown in figure 1, the flow through a 3/8-inch tip is 29.5 gal/min at 50 psi, and the flow through the same tip at 25 psi is 21 gal/min (21/29.5 = 0.71, a reduction of 71 percent).

## Conclusion

Engine operators must make a reasonable estimate of friction loss in order to set pump discharge pressure properly. Friction loss depends on hose size and length, flow rate, and internal hose roughness. Increasing the hose size and/or reducing the flow rate will decrease friction loss. Appliances should be ignored when estimating friction loss. Two methods can be used to determine friction loss – friction-loss calculators and friction-loss tables. For more accurate values, friction loss can be calculated using the method explained in appendix C.

## Appendix A

### Rules of Thumb for Fireline Hydraulics

**A. Pressure:**

| | | |
|---|---|---|
| 1 psi | = | 2 feet of water lift |
| 2 feet of head | = | 1 psi |
| 50 feet of head | = | 25 psi |
| 100 feet of head | = | 50 psi |
| Atmospheric pressure | = | 14.7 psi at sea level |
| | | 29.92 inches of mercury (Hg) |
| 1,000 foot elevation gain | = | ½ psi decrease in atmospheric pressure |
| | = | 1 inch of Mercury (Hg) decrease in atmospheric pressure* |

**B. Drafting:**

| | | |
|---|---|---|
| 1 inch of Mercury (Hg) | = | 1 foot of lift |
| Maximum theoretical lift | = | 33.9 feet at sea level |
| Good serviceable pump | = | 22 feet of lift at sea level |
| | = | 15 feet of lift at 8,000 feet |

**C. Nozzle Pressure:**

| | | |
|---|---|---|
| Tips (except master streams) | = | 50 psi |
| Region 5 Forester (twin tip) nozzle | = | 50 psi |
| Combination/fog nozzle | = | 100 psi |

**D. Water Weight and Volumes:**

| | | |
|---|---|---|
| Weight of water | = | 8 pounds per gallon |
| Volume of water in 100-foot length of fire hose | = | 4 gallons for 1-inch hose |
| | = | 9 gallons for 1-1/2-inch hose |

* also said as "1- inch loss of vacuum"

## Appendix B

**Technical Information on Friction Loss**
When water flows through fire hose and fire fittings there is a loss of pressure caused by the rubbing of water along the walls of the fire hose and fittings and also the turbulence of the water. This is called “friction loss.” Friction loss in fire hose and pipe generally follows certain relationships. These relationships are:

1. *Friction loss is approximately inversely proportional to the fifth power of the diameter.*
   This means that a small change in hose size will drastically change the friction loss (for a given flow). Another way is of saying this is, the bigger the hose with the same flow rate the smaller the friction loss. One-inch hose has approximately seven times the friction loss of 1½-inch hose. Doubling the inside diameter of a hose reduces the theoretical friction loss for a given flow to one thirty-secondth (1/32).

2. *Friction loss varies approximately as the square of the flow (gal/min).*
   This means that friction loss increases more rapidly than the increase in flow. For example, if the flow is doubled, the friction loss becomes four times (2 times 2) as much as it was originally. If the flow is tripled, then the friction loss becomes nine times (3 times 3) as much. If the flow is quadrupled, then the friction loss becomes 16 times (4 times 4) as it was originally.

3. *Friction loss is affected by roughness of the inside of the hose in relation to the diameter.*
   The rougher the hose, the greater the friction loss. The smaller the hose with the same roughness, the greater the friction loss. A very rough (inside) hose can have double the friction loss of a smooth (inside) hose of the same size.

4. *Friction loss is directly proportional to length.*
   Friction loss in 500 feet of hose will be five times the friction loss in 100 feet of the same size and type of hose. (If you double the length of the hose, you will double the friction loss.)

5. *Friction loss is nearly independent of pressure.*
   For a given flow, the friction loss in hose is nearly the same regardless of the pressure. This means that when water is flowing through a hose at a fixed rate, the friction loss is the same whether the pressure is 50 or 400 psi.

## Appendix C

### Calculating Friction Loss

Accurate estimation of friction loss requires detailed information. In the 1940s, Lewis F. Moody, a Princeton University professor, developed a chart called a "Moody Diagram." The Moody diagram maps the friction loss of fluids flowing in pipes. The Reynolds number, relative roughness of the pipe, rate of flow, pipe diameter, and the fluid viscosity must be determined before using the Moody diagram. This chart and related calculations are far beyond what could be done on a fire line and is also beyond what is required from a practical sense. A reasonable estimate of friction loss can be made by an equation developed from the Moody diagram:

$$FL = C(Q/100)^2(L/100)$$

Where:

- FL = Friction loss
- C = Friction loss coefficient for the size and type of hose
- Q = gallons per minute
- L = hose-lay length in feet

The friction loss coefficient (C) is a number specific to a hose diameter and type (inside roughness). A small change in diameter will change the friction-loss coefficient markedly, and a change in the inside roughness will also change the friction-loss coefficient. The friction-loss coefficient will experience some change with changes in flow rate, slightly decreasing with an increase in the flow rate. This means there is not one friction-loss coefficient (C) that applies to a given hose size because of differences in hose roughness and flow rates. Generally accepted average values for "C" can be found in fire publications.

SDTDC performed tests on a number of hose sizes and types and found that the generally accepted published values were close to the values from SDTDC tests except for the 1-inch hose and, to a lesser extent, 1½-inch hose. Listed below are the generally accepted published values, SDTDC test ranges, and recommended practical-use values. The use of this equation, and the practical-use friction-loss coefficients (C), provide reasonable estimates of expected friction losses in a hose lay.

Note that most commercially available friction-loss calculators use "published values" to determine friction loss.

**Friction-Loss Coefficients (C):**

| Hose Diameter (inch) | Published Values[1] | SDTDC Test Range | Practical Use* |
|---|---|---|---|
| ⅝ | ----- | 1,931 | 2,000 |
| ¾ | 1,100 | 1,040 to 1,325 | 1,100 |
| 1 | 150 | 163 to 382 | 250 |
| 1½ | 24 | 19 to 42 | 35 |
| 1¾ | 15.5 | 14 | 14 |
| 2½ | 2 | NA | 2 |

* Values used to determine friction loss in tables 1 and 2.

To determine the friction-loss coefficient "C" used on a particular friction-loss calculator, use the following procedure: Set the flow rate to 100 gal/min and read friction loss (in psi per 100 feet) for each hose size. *The friction loss at 100 gal/min is the "C" that was used for that hose size, on that particular calculator.*

Referring to table 2, note that the friction-loss values for 100 gal/min (in the far right column) are also the friction-loss coefficients "C" used to calculate each friction loss value within the table.

(Footnotes)

[1] National Fire Protection Association (NFPA) Fire Protection Handbook 16th Edition, IFSTA Fire Protection Publications – Fire Stream Practices 7th Edition.

## About the Authors

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For additional information on this comparison study, contact Dave Haston at SDTDC. Phone: 909-599-1267 ext. 294; or by e-mail at dhaston@fs.fed.us.

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