

DPO Hydraulics Refresher

References:

Pumping Apparatus Driver/Operator Handbook-IFSTA
Essentials of Firefighting Handbook-IFSTA
Fire Stream Practices-IFSTA

INTRODUCTION

To produce effective fire streams, it is necessary to have an understanding of basic hydraulic theories and principles. In order to establish and maintain effective and efficient fire streams, the pump operator needs to know the nozzle pressure, the GPM flow, the amount of friction loss in the fire hose, the friction loss in appliances and any pressure loss or gain due to elevation changes.

Net Pump Discharge Pressure (NPDP) Is the end result of hoseline calculations. It is equal to Nozzle Pressure + Friction Loss in the hose + Friction loss in Appliances + Pressure due to Elevation Changes.

$$EP = NP + FL + \text{Appliance} \pm \text{Elevation}$$

Nozzle Pressure (NP) The amount of pressure required at the nozzle to produce an effective fire stream.

Fog nozzle (handline/master) 100 psi

Low pressure fog nozzle 75 psi

Solid stream handline 50 psi

Solid stream master 80 psi

Friction Loss (FL) The part of the total pressure lost while forcing water through pipe, hose, fittings, adapters, and appliances. The basis for fire hose friction loss calculations are the size of the hose, the amount of water flowing (gpm), the length of the hose lay, the age of hose,

and the condition of the lining. These factors give rise to the formula for computing friction loss:

$$FL = C \cdot Q^2 \cdot L$$

Where: FL = friction loss in psi

C = coefficient (constant factor - see below)

Q = flow rate in gallons per minute/100

L = hose length in feet/100

Friction Loss Coefficients (C):

1³/₄" - 15.5

2¹/₂" - 2.0

3" - .80

4" - .20

Example 1: If 200 gpm is flowing from a nozzle, what is the friction loss in 200 ft. of 2¹/₂" hose?

$$FL = C \cdot Q^2 \cdot L$$

$$C = 2$$

$$Q = \text{gpm}/100 = 200/100 = 2$$

$$L = \text{length}/100 = 200/100 = 2$$

$$FL = (2) (2)^2 (2)$$

$$FL = (2) (4) (2)$$

$$FL = (8) (2)$$

$$FL = 16 \text{ psi}$$

Note: FL is the total friction loss

Example 2: If 150 gpm is flowing through 200 ft. of 1³/₄" hose, what is the friction loss from the hose?

$$FL = C \cdot Q^2 \cdot L$$

$$C = 15.5$$

$$Q = \text{gpm}/100 = 150/100 = 1.5$$

$$L = \text{length}/100 = 200/100 = 2$$

$$FL = (15.5) (1.5)^2 (2)$$

$$FL = (15.5) (2.25) (2)$$

$$FL = (34.875) (2)$$

$$FL = 69.75 \text{ psi (round to 70 psi)}$$

GPM Formula - It is possible to determine water flow from any solid stream nozzle when the nozzle pressure and tip diameters are known. The following formula is used to determine the GPM flow of solid stream nozzles.

$$\text{GPM} = 29.7 \cdot d^2 \cdot \sqrt{\text{NP}}$$

Where: GPM = discharge in gallons per minute

29.7 = a constant

d = diameter of the tip measured in inches

NP = nozzle pressure in psi

Example 1: Determine the water flow from a 2" tip master stream nozzle operating at 80 psi nozzle pressure.

$$\text{GPM} = 29.7 \cdot d^2 \cdot \sqrt{\text{NP}}$$

$$= (29.7) (2)^2 (\sqrt{80}) \text{ (Use 81 for square root purposes)}$$

$$= (29.7) (4) (9)$$

$$= (118.8) (9)$$

$$= 1069.2 \text{ GPM (1070)}$$

Example 2: Determine the GPM flow from a 1 1/8" tip handline at 50 psi nozzle pressure.

$$\text{GPM} = 29.7 \cdot d^2 \cdot \sqrt{\text{NP}}$$

$$= (29.7) (1.125)^2 (\sqrt{50}) \text{ (Use 49 for square root purposes)}$$

$$= (29.7) (1.265) (7)$$

$$= (37.57) (7)$$

= 262.99 GPM (265)

Solid Stream Handline @ 50 psi

Tip Size GPM

1" 210

1 $\frac{1}{8}$ " 265

1 $\frac{1}{4}$ " 325

Solid Stream Master @ 80 psi

Tip Size GPM

1 $\frac{1}{2}$ " 600

1 $\frac{3}{4}$ " 800

2" 1000

2 $\frac{1}{4}$ " 1345

2 $\frac{3}{8}$ " 1500

2 $\frac{1}{2}$ " 1660

Appliances - Fire ground operations sometimes require the use of hose line appliances. These appliances include reducers, wyes, manifolds, and heavy stream piping. In situations where total gpm is less than 350 gpm, the friction loss is insignificant. If total gpm is greater than 350 gpm, add 10 psi for friction loss in the appliance. Master stream appliances flowing at rated capacity use 25 psi per appliance.

Standpipe - When pumping into a standpipe, do not add friction loss for the piping because it is insignificant. Allow for elevation only.

Elevation Pressure - When a nozzle is operating at an elevation higher than the discharge, elevation pressure is exerted back against the pump. To compensate for this pressure loss, elevation pressure must be added to the total pressure loss. Operating a nozzle below the discharge results in negative pressure against the pump. In this case, pressure has to be subtracted from the total pressure loss.

Elevation pressure = 0.5 psi/foot elevation

or 5 psi per floor of elevation

Net Pump Discharge Pressure: NPDP = NP + FL + Appliance \pm Elevation

Example 1: What is the engine pressure (NPDP) for 200 ft. of 1¾" hose flowing 200 gpm, with a low-pressure fog nozzle, on the third floor?

$$\text{NPDP} = \text{NP} + \text{FL} + \text{Appliance} \pm \text{Elevation}$$

Nozzle Pressure - Low-Pressure Fog = 75 psi Coefficients

$$1\frac{3}{4}" - 15.5$$

Friction Loss = $C \cdot Q^2 \cdot L$ C = Coefficient 2½" - 2.0

$$\text{FL} = (15.5) (2)^2 (2) \quad Q = \text{Flow rate gpm}/100 \quad 3" - .80$$

$$\text{FL} = 125 \quad L = \text{Hose length}/100 \quad 4" - .20$$

$$\text{NP} = 75$$

$$\text{FL} = 125$$

$$\text{Appliance} = 0$$

$$\text{Elevation} = 15$$

$$\text{EP} = 75 + 125 + 0 + 15$$

$$\text{EP} = 215 \text{ psi}$$

Example 2: What is the engine pressure (NPDP) for 300 ft. of 2½" hose with a 1⅛" solid stream tip handline.

$$\text{NPDP} = \text{NP} + \text{FL} + \text{Appliance} \pm \text{Elevation}$$

Nozzle Pressure - Solid Stream Handline = 50 psi

$$\text{GPM} = 29.7 \cdot d^2 \cdot \sqrt{\text{NP}}$$

$$= (29.7) (1.125)^2 (\sqrt{50}) \quad (\text{Use } 49 \text{ for square root purposes}) = (29.7) (1.265) (7)$$

$$= (37.57) (7)$$

$$= 262.99 \text{ GPM (265)}$$

Coefficients

1³/₄" - 15.5

Friction Loss = C·Q²·L C = Coefficient 2¹/₂" - 2.0

FL = (2) (2.65)² (3) Q = Flow rate gpm/100 3" - .80

FL = 42.135 L = Hose length/100 4" - .20

NP = 50

FL = 42 EP = 50 + 42 + 0 + 0

Appliance = 0 EP = 92 psi

Elevation = 0

Wye Hoselines

A more complex pumping situation occurs when determining the engine pressure while pumping into a line that supplies a gated wye that branches into two or more smaller attack lines. This scenario will probably occur when pumping into the Leader Line. If the nozzle pressure, hose length and diameter are the same on the attack lines, then calculate the friction loss for one attack line only. This calculation will then be added with the friction loss for the supply line to the wye when determining the engine pressure. If any of the attack lines are utilizing different nozzle pressures, hose lengths, or diameters, then the line with the highest friction loss is the line used to determine the friction loss for the attack lines. The lines that have a lesser friction loss are then gated back at the appliance. Communication with the crews on the lines gated down is important since there are no pressure gauges on the wyes.

NPDP = NP + FL(supply) + Appliance(10 psi if over 350 gpm) + FL(attack) ±
Elevation

Example 1: A pumper is pumping into a 200 ft., 4" Leader Line, that is using a gated wye to supply three (3), 1³/₄" attack lines that are on the third floor. The attack lines are 150 ft. each, with adjustable flow nozzles set on 125 gpm. What is the engine pressure (NPDP) for this hose lay?

NPDP = NP + FL(supply) + Appliance(10 psi if over 350 gpm) + FL(attack) ±
Elevation

Nozzle pressure - Fog Handline = 100 psi

FL for a 200 ft. 4" apartment lay flowing 375 gpm.

$$FL = C \cdot Q^2 \cdot L$$

$$FL = (.20) (3.75)^2 (2)$$

$$FL = 5.625 \text{ psi}$$

GPM Flow = 3 lines @ 125 gpm each = 375 gpm.

Appliance Loss = 10 psi

Note: Since the attack lines are the same, use the FL for only one line in the equation.

FL for 150 ft. of 1 $\frac{3}{4}$ " hose flowing 125 gpm.

$$FL = C \cdot Q^2 \cdot L$$

$$FL = (15.5) (1.25)^2 (1.5)$$

$$FL = 36.328$$

Elevation = 15 psi

$$EP = 100 + 5.625 + 10 + 36.328 + 15$$

$$EP = 166.953$$

Example 2: A pumper is pumping into 400 ft. of 4" hose that is using a gated wye to supply three attack lines. The attack lines are as follows:

1. 150ft. of 1 $\frac{3}{4}$ " hose with a 200 GPM fog nozzle.
2. 200ft. of 1 $\frac{3}{4}$ " hose with a 150 GPM low-pressure fog nozzle.
3. 250ft. of 2 $\frac{1}{2}$ " hose with a 1 $\frac{1}{8}$ " solid stream handline. (GPM = $29.7 \text{od}^2 \text{ovNP} = 265$)

What is the engine pressure (NPDP) for this hose lay?

$$\text{NPDP} = \text{NP} + \text{FL}(\text{supply}) + \text{Appliance}(10 \text{ psi if over } 350 \text{ gpm}) + \text{FL}(\text{attack}) \pm \text{Elevation}$$

$$\text{Nozzle pressure - Fog Handline} = 100 \text{ psi}$$

$$\text{Low-pressure fog handline} = 75 \text{ psi}$$

$$\text{Solid stream handline} = 50 \text{ psi}$$

FL for 400 ft. 4" hose flowing 615 gpm.

$$\text{FL} = C \cdot Q^2 \cdot L$$

$$\text{FL} = (.20) (6.15)^2 (4)$$

$$\text{FL} = 30.258 \text{ psi}$$

GPM Flow = 3 lines totaling 615 gpm.

Appliance Loss = 10 psi

Determine which line has the highest friction loss.

Line 1- FL for 150 ft. of 1¾" hose flowing 200 gpm.

$$\text{FL} = C \cdot Q^2 \cdot L$$

$$\text{FL} = (15.5) (2)^2 (1.5)$$

$$\text{FL} = 93 \text{ psi}$$

Line 2- FL for 200 ft. of 1¾" hose flowing 150 gpm.

$$\text{FL} = C \cdot Q^2 \cdot L$$

$$\text{FL} = (15.5) (1.5)^2 (2)$$

$$\text{FL} = 69.75 \text{ psi}$$

Line 3- FL for 250 ft. of 2½" hose flowing 265 gpm.

$$\text{FL} = C \cdot Q^2 \cdot L$$

$$FL = (2.0) (2.65)^2 (2.5)$$

$$FL = 35.113\text{psi}$$

Line 1 has the highest friction loss. Use this friction loss and nozzle pressure in the equation to determine the engine pressure. Gate back the pressures for other lines at the gated wye. Communicate with the crews on the lines that are gated back.

$$EP = 100 + 30.258 + 10 + 93 + 0$$

$$EP = 233.258$$

Pressure vs. Volume

A common misconception in the fire service is that if you boost the pressure of the water being discharged, the volume of water will increase. This is true to a point. On each pumper there is a placard that rates that particular pumper at 150, 200, and 250 psi. Pumpers are rated at their maximum capacity at 150 psi pump pressure from draft. With a positive pressure source, a centrifugal pump takes advantage of the incoming pressure. Therefore, a pumper can pump 150 psi (+) the incoming pressure and maintain its rated capacity. For example: 150 psi net pump pressure + 45 psi incoming pressure = 195 psi discharge pressure and still maintain its rated capacity. An increase in pressure above 150 psi net pump pressure actually decreases the amount of water flowing.

Calculating Additional Water from a Hydrant

When a pumper is connected to a hydrant and is not discharging water, the pressure shown on the intake gauge is the static pressure. When the pumper is discharging water, the pressure shown on the intake side is the residual pressure. The difference between the two pressures is used to determine how much water is available, and consequently the number of additional lines of the same size, that can be added and supplied with efficient water. To use this method, the pump operator has to convert this drop in pressure to a percentage. Use the following formula to determine the percentage.

$$\text{Percent drop} = \frac{(\text{Static} - \text{Residual})}{\text{Static}}(100)$$

Static

EXAMPLE:

A pumper is supplying one line with 250 gpm flowing. The static pressure was 70 psi and the residual pressure reading is 63 psi. Determine how many additional lines may be added.

$$\text{Percent drop} = \frac{(\text{Static} - \text{Residual})}{\text{Static}}(100)$$

Static

$$\text{Percent drop} = \frac{70 - 63}{70}(100)$$

70

$$\text{Percent drop} = 10 \%$$

WATER AVAILABLE TABLE

Percent Decrease Water Available

0 - 10 % 3 times amount being delivered

11 - 15% 2 times amount being delivered

16 - 25% same as being delivered

Over 25% less than is being delivered

Three times the amount of water already being delivered is available for additional lines. It is possible to add any combination of hand lines or master streams as long as they do not exceed 750 GPM. (250 x 3 = 750).

Note: By connecting all three outlets of the hydrant to the pumper with large diameter hose, the maximum capability of the hydrant will be available for use.

Summary

In order to produce effective hose streams it is necessary to have a working knowledge of hydraulics. The pump operator needs to know the nozzle pressure, GPM flow, friction loss in the hose, friction loss in appliances and any pressure loss or gain due to elevation changes.

This lesson was developed to ensure that the most effective and efficient fire streams are utilized.

Addendum 1

Water Supply Calculations

Hose Friction Loss (psi per 100')					Solid Stream Master (80 psi)		Solid Stream Handline (50 psi)	
	Hose Size				Tip Size	GPM	Tip Size	GPM
GPM	1 3/4	2 1/2	3	4				
95	14				1 1/2	600	1	
125	24				1 3/4	800	1 1/8	
150	35				2	1000	1 1/4	
175	47	6			2 1/4	1345	GPM Calculation using the formula GPM=29.7 d ² /N	
200	62	8			2 3/8	1500		
225		10			2 1/2	1660		
250		13	5					
275		15						
300		18						
325		22	8					
350		25						
500			20	5				
750			45	11				
1000			60	20				
1250				31				
1500				45				
1750				61				
Friction Loss Calculations Using The Formula FL=CQ ² L								