LESSON PLAN #PO-1A

TITLE: **HYDRAULICS (Part I)**

TIME REQ'D: Eight (8) Hours:
Four (4) hours classroom
Four (4) hours drill ground

STANDARD: NFPA 1002 (1998 Edition)

INST. LEVEL: Levels 1 - 2 - 3
Knowledge - Comprehension - Application

MAT. NEEDED: Classroom:
- Overhead Projector
- Screen
- Hydraulics (Part I) Overhead Transparencies
- Appropriate Markers
- Hydraulics (Part I) Student Manuals
- Portable Calculator for each Student
- Student Evaluations
- Flipchart / Chalkboard (optional)

Drill Ground:
- Pumping Apparatus
- Master Stream Appliances
- Appropriate Sizes and Quantity of Hose
- Inline Pressure Gauges
- Nozzles (Master Stream and Handline)
- Flow Test Kit (optional)

REFERENCE: IFSTA "Fire Stream Practices", 7th Edition
IFSTA "Pumping Apparatus", 7th Edition
IFSTA "Water Supplies", 4th Edition
Fire Service Hydraulics, 2nd Edition

OBJECTIVE: At the end of this class the apparatus operator shall be able to:
SM Pg 1

1. Define the following terms as they relate to fire service hydraulics:

a. Atmospheric Pressure
b. Capacity
c. Displacement
d. Flow (GPM)
e. Flow Pressure
f. Friction Loss (FL)
g. Head Pressure
h. Hydrant Pressure
i. Negative Pressure
j. Net Engine Pressure
k. Normal Operating Pressure
l. Nozzle Reaction
m. Pounds Per Square Inch (PSI)
n. Pump Discharge Pressure (PDP)
o. Residual Pressure
p. Static Pressure
q. Vacuum
r. Velocity
s. Water Hammer

2. Determine the following:
   a. Friction loss in siamesed lines when the size of hose and gpm flow are given
   b. Nozzle or pump discharge pressures when the length and size of hose and size of nozzle are given
   c. Friction loss in the supply and attack lines (used by the department) when the gpm flow is given
   d. Water flow in gallons per minute when the diameter of the orifice and pressure at the orifice are given

There will be a written test based on the objectives at the end of the classroom portion of this course. A minimum score of 70% is required. Additionally, given the appropriate apparatus and hose, the student shall demonstrate how to mentally calculate friction loss.

MOTIVATION: Water is the most widely used suppression agent in the world. It is cheap, easily attainable and absorbs tremendous amounts of heat. Fire departments rely heavily on waters ability to extinguish fires. You, the apparatus operator, are a key element in water supply at the emergency scene. It's up to you to see that nozzles are supplied with sufficient water and pressure to develop effective firestreams. A basic understanding of hydraulics is essential to accomplish that task.

OVERVIEW: In this presentation we will cover:

OHT #H1

1. Nineteen (19) fire service hydraulics terms
2. Five (5) written mathematical formulas
3. Two (2) mental formulas for calculating friction loss on the fire ground

SM Pg 2

PRESENTATION: I. FIRE SERVICE HYDRAULICS TERMINOLOGY

A. Atmospheric Pressure

OHT #H2

1. Atmosphere around earth has depth and density - exerts pressure on everything on earth

2. Greatest at lower altitudes where air is heavier - 14.7 psi at sea level

B. Capacity

OHT #H3

1. Maximum ability of pump or water distribution system to deliver water

C. Displacement

OHT #H4

1. Amount of water drawn into pump -displacing air

2. Volume of water displaced by stroke of positive displacement pump

D. Flow (GPM)

OHT #H5

1. Quantity of water discharged through an orifice

E. Flow Pressure

OHT #H6

1. Forward velocity pressure at discharge opening while water is flowing

2. Measured by using pitot tube and gauge

F. Friction Loss

OHT #H7

1. Result of two surfaces rubbing together

2. Flowing water rubbing against its container

3. Higher the pressure - the greater the friction loss

G. Head Pressure

OHT #H8

1. Downward pressure exerted by column of water

2. Determined by height of water supply above discharge orifice

3. Column of water 2.304 ft. high will create 1# pressure at the base

4. Column of water 1 ft. high will create .434# pressure at the base

5. To calculate head pressure do either one of the following:

a. Divide height of water by 2.304

b. Multiply height of water by .434

H. Hydrant Pressure

OHT #H9

1. Pressure of water at hydrant

a. Amount of pressure water system is exerting on pump

b. Will read on compound gauge of pump panel

I. Negative Pressure

OHT #H10

1. Any pressure less than normal operating pressure

2. Negative pressure is created every time hydrant is opened

a. Example:

(1) water runs from homes back to mainline until pressure equalizes

J. Net Engine Pressure

OHT #H11

1. Total work the pump must do

2. Calculated by subtracting intake pressure from discharge pressure

NOTE

SINCE THERE IS NOTHING TO BLOCK THE WATER FLOW BETWEEN THE INTAKE AND OUTLET OF A CENTRIFUGAL PUMP, WATER UNDER PRESSURE WILL FLOW THROUGH THE IMPELLER AND OUT THE PUMP DISCHARGE WITHOUT THE IMPELLER EVEN TURNING. MOVEMENT OF THE IMPELLER ONLY INCREASES THE VELOCITY AND PRESSURE INSIDE THE VOLUTE. SINCE THE INCOMING PRESSURE ADDS DIRECTLY TO THE PRESSURE DEVELOPED BY THE PUMP, THE PUMP DOES NOT HAVE TO DO AS MUCH WORK TO OBTAIN THE SAME DISCHARGE PRESSURES AS IT WOULD WHEN DRAFTING FROM A STATIC WATER SUPPLY.

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K. Normal Operating Pressure

OHT #H12

1. Pressure found in water distribution system during normal consumption demands

2. When water moves, static pressure ceases to exist

3. Difference between static pressure and normal operating pressure is:

   a. Friction loss caused by water flowing through various pipes, valves, and fittings.

L. Nozzle Reaction

OHT #H13

1. Backward thrust of water equal to discharge velocity and flow

2. Forward movement of nozzle when discharge velocity and flow are decreased

3. Law of Physics

   a. For each action there is an equal and opposite reaction

M. Pounds Per Square Inch (PSI)

OHT #H14

1. Unit of measure for:

   a. Pressure

   b. Velocity

2. Amount of force exerted on one (1) square inch of surface area

N. Pump Discharge Pressure

OHT #H15

1. Pressure at discharge port of pump

2. Sum of hydrant pressure and net engine pressure

O. Residual Pressure

OHT #H16

1. That part of total available pressure not used to overcome friction loss or gravity while forcing water through pipe, fittings, fire hose, and adapters

2. Residual means:

   a. Remainder

   b. What is left

3. Example:

   a. When flowing fire hydrants, residual pressure is:

      (1) pressure left in system to supply additional water

P. Static Pressure

OHT #H17

1. Stored potential energy available to force water through pipe, fittings, fire hose, and adapters

2. Static means:

   a. At rest

   b. Without motion

3. If water not moving, pressure exerted is static

4. Always some flow in municipal water systems

   a. Domestic needs

   b. Industrial uses

   c. Leaks

5. For fire department purposes, water system pressure before hydrant flow is static pressure

Q. Vacuum

OHT #H18

1. Any pressure less than atmospheric

R. Velocity

OHT #H19

1. Speed of water as it leaves orifice

2. Measured in PSI

S. Water Hammer

OHT #H20

1. Pressure surges resulting from sudden starting and stopping of water flow

INSTRUCTOR NOTE

APPARATUS OPERATOR STANDARD #16-06.02 REQUIRES EACH STUDENT TO CALCULATE VARIOUS PROBLEMS USING THE FOLLOWING FORMULAS. THE LESSON PLAN IS SET UP TO FIRST GIVE THE APPLICABLE FORMULA(S) AND DESCRIBE ITS COMPONENTS. THE NEXT STEP LEADS THE STUDENTS THROUGH A PRACTICE PROBLEM FOUND IN THEIR STUDENT MANUALS. THIS PRACTICE PROBLEM IS ALREADY WORKED OUT AND THEY SEE WHERE THE NUMBERS FIT INTO THE FORMULA. THIS EXAMPLE IS FOLLOWED BY SEVERAL PROBLEMS THAT NEED TO BE WORKED BY THE STUDENTS. EACH PROBLEM SHOULD BE DONE BY THE STUDENTS (EITHER INDIVIDUALLY OR IN SMALL GROUPS) AND GONE OVER. TRANSPARENCIES HAVE BEEN INCLUDED TO ALLOW INSTRUCTOR TO WRITE DOWN THE SOLUTION AS IT IS GIVEN BY THE STUDENTS. IT SHOULD FOLLOW THE WORK GIVEN FOR ALL THE PROBLEMS IN THE INSTRUCTOR GUIDE. COMPLETE AS MANY PROBLEMS AS NEEDED FOR ALL STUDENTS TO GAIN COMPREHENSION OF WHAT THEY ARE DOING.

II. WRITTEN FORMULAS

SM Pg 4

A. Area of Circle

INSTRUCTOR NOTE
STUDENTS SHOULD KNOW HOW TO USE BOTH FORMULAS TO FIND THE AREA OF A CIRCLE, BUT MAY USE WHICHEVER ONE THEY FEEL MOST COMFORTABLE WITH.

1. Formulas to find area of circle

OHT #H21

a. $A = \pi r^2$

(1) **A** is area

(2) **π** equals 3.14

(3) **r** is radius

b. $A = \pi d^2 \div 4$

(1) **A** is area

(2) **π** equals 3.14

(3) **d** is diameter

2. To find area of discharge port 2 1/2" in diameter (student manual example)

OHT #H22

a. $A = \pi r^2$

(1) $A = (3.14)(1.25)^2$

(2) $A = 3.14 \times 1.5625$

(3) $A = 4.90625$ SQ. IN.

b. $A = \pi d^2 \div 4$

OHT #H23

(1) $A = (3.14)(2.5)^2 \div 4$

(2) $A = 3.14 \times 6.25 \div 4$

(3) $A = 19.625 \div 4$

(4) $A = 4.90625$ SQ. IN.

3. Find area of nozzle whose diameter is 1 3/4" (first student problem - work through with class)

OHT #H24

a. $A = \pi r^2$

(1) $A = (3.14)(.875)^2$

(2) $A = 3.14 \times .765625$

(3) $A = 2.4040625$ SQ. IN.

OHT #25

b. $A = \pi d^2 \div 4$

(1) $A = (3.14)(1.75)^2 \div 4$

(2) $A = 3.14 \times 3.0625 \div 4$

(3) $A = 9.61625 \div 4$

(4) $A = 2.4040625$ SQ. IN.

4. Find water surface area in 45' diameter storage tank

OHT #26

a. $A = \pi r^2$

(1) $A = (3.14)(22.5)^2$

(2) $A = 3.14 \times 506.25$

(3) $A = 1{,}589.625$ SQ. FT.

b. $A = \pi d^2 \div 4$

(1) $A = (3.14)(45)^2 \div 4$

(2) $A = 3.14 \times 2{,}025 \div 4$

(3) $A = 6{,}358.5 \div 4$

(4) $A = 1{,}589.625$ SQ. FT.

5. Find water surface area in 10' diameter stock tank

a. $A = \pi r^2$

(1) $A = (3.14)(5)^2$

(2) $A = 3.14 \times 25$

(3) $A = 78.5$ SQ. FT.

b. $A = \pi d^2 \div 4$

(1) $A = (3.14)(10)^2 \div 4$

(2) $A = 3.14 \times 100 \div 4$

(3) $A = 314 \div 4$

(4) $A = 78.5$ SQ. FT.

6. Find water surface area in 150' diameter pond

a. $A = \pi r^2$

(1) $(3.14)(75)^2$

(2) $3.14 \times 5{,}625$

(3) 17,662.5 SQ. FT.

b. $A = \pi d^2 \div 4$

(1) $(3.14)(150)^2 \div 4$

(2) $3.14 \times 22{,}500 \div 4$

(3) $70{,}650 \div 4$

(4) 17,662.5 SQ. FT.

7. Find area of discharge port 5" in diameter

a. $A = \pi r^2$

(1) $(3.14)(2.5)^2$

(2) 3.14×6.25

(3) 19.625 SQ. IN.

b. $A = \pi d^2 \div 4$

(1) $A = (3.14)(5)^2 \div 4$

(2) $A = 3.14 \times 25 \div 4$

(3) $A = 78.5 \div 4$

(4) $A = 19.625$ SQ. IN.

8. Find area of nozzle 2" in diameter

a. $A = \pi r^2$

(1) $A = (3.14)(1)^2$

(2) $A = 3.14 \times 1$

(3) $A = 3.14$ SQ. IN.

b. $A = \pi d^2 \div 4$

(1) $A = (3.14)(2)^2 \div 4$

(2) $A = 3.14 \times 4 \div 4$

(3) $A = 12.56 \div 4$

(4) $A = 3.14$ SQ. IN.

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B. Capacity of Cylinder (In Gallons)

INSTRUCTOR NOTE

STUDENTS SHOULD KNOW HOW TO USE BOTH FORMULAS TO FIND THE CAPACITY OF A CYLINDER, BUT MAY USE WHICHEVER ONE THEY FEEL MOST COMFORTABLE WITH.

1. Formulas to find capacity (in gallons) of cylindrical tank:

OHT #27

a. SHORT FORMULA (approximate)

(1) GALLONS = $d^2 6L$

(a) **d** is diameter

(b) **L** is length

b. LONG FORMULA (exact)

(1) CUBIC FEET (ft^3) = $\pi r^2 L$

(a) π equals 3.14

(b) **r** is radius

(c) **L** is length

(2) GALLONS = ft^3 x 7.48

2. Find capacity of cylindrical tank 10' diameter and 15' long (student manual example)

OHT #H28

a. $G = d^2 6L$

(1) $G = (10)^2(6)(15)$

(2) G = 100 x 6 x 15

(3) G = 9,000 GALLONS

b. $ft^3 = \pi r^2 L$ ❖ G = ft^3 x 7.48

OHT #H29

(1) $ft^3 = (3.14)(5)^2(15)$

(2) ft^3 = 3.14 x 25 x 15

(3) ft^3 = 1,177.5 CU. FT.

(4) G = 1,177.5 x 7.48

(5) G = 8,807.7 GALLONS

3. Find capacity of cylindrical tank 45' long and 23' in diameter (first student problem - work through with class)

OHT #H30

a. $G = d^2 6L$

(1) $G = (23)^2(6)(45)$

(2) G = 529 X 6 X 45

(3) G = 142,830 GALLONS

b. $ft^3 = \pi r^2 L$ ❖ $G = ft^3 \times 7.48$

OHT #H31

(1) $ft^3 = (3.14)(11.5)^2(45)$

(2) $ft^3 = 3.14 \times 132.25 \times 45$

(3) $ft^3 = 18{,}686.925$ CU. FT.

(4) G = 18,686.925 X 7.48

(5) G = 139,778.19 GALLONS

4. Find capacity of stock water trough 12' in diameter and 2' high

OHT #H32

a. $G = d^2 6L$

(1) $G = (12)^2(6)(2)$

(2) G = 144 X 6 X 2

(3) G = 1,728 GALLONS

b. $ft^3 = \pi r^2 L$ ❖ $G = ft^3 \times 7.48$

(1) $ft^3 = (3.14)(6)^2(2)$

(2) $ft^3 = 3.14 \times 36 \times 2$

(3) $ft^3 = 226.08$ CU. FT.

(4) G = 226.08 X 7.48

(5) G = 1,691.0784 GALLONS

5. Find capacity of swimming pool 24' in diameter and 4' deep

a. $G = d^2 6L$

(1) $G = (24)^2(6)(4)$

(2) G = 576 X 6 X 4

(3) G = 13,824 GALLONS

b. $ft^3 = \pi r^2 L$ ❖ G = ft^3 x 7.48

(1) $ft^3 = (3.14)(12)^2(4)$

(2) ft^3 = 3.14 X 144 X 4

(3) ft^3 = 1,808.64 CU. FT.

(4) G = 1,808.64 X 7.48

(5) G = 13,528.627 GALLONS

6. Find capacity of cistern 15' in diameter and 12' deep

a. $G = d^2 6L$

(1) $G = (15)^2(6)(12)$

(2) G = 225 X 6 X 12

(3) G = 16,200 GALLONS

b. $ft^3 = \pi r^2 L$ ❖ G = ft^3 x 7.48

(1) $ft^3 = (3.14)(7.5)^2(12)$

(2) ft^3 = 3.14 X 56.25 X 12

(3) ft^3 = 2,119.5 CU. FT.

(4) G = 2,119.5 X 7.48

(5) G = 15,853.86 GALLONS

C. Water Flow (In GPM)

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1. Formula to calculate water flow in Gallons Per Minute (GPM):

OHT #H33

a. $GPM = 29.7d^2\sqrt{P}$

(1) **GPM** is gallons per minute

(2) **d** is diameter

(3) **P** is discharge or flow pressure

2. Find GPM flow from 1" nozzle at 60 PSI (student manual example)

OHT #H34

a. $GPM = 29.7d^2\sqrt{P}$

(1) $GPM = (29.7)(1)^2 \sqrt{60}$

(2) GPM = 29.7 X 1 X 7.7460

(3) GPM = 230.0562

3. Find GPM flow from 1 5/8" nozzle at 55 PSI (student manual example)

OHT #H35 **(does not show work)**

a. $GPM = 29.7d^2\sqrt{P}$

(1) $GPM = (29.7)(1.625)^2 \sqrt{55}$

(2) GPM = 29.7 X 2.640625 X 7.4161984

(3) GPM = 581.62592

4. Find GPM flow from 2" master stream tip operating at 95 PSI

a. $GPM = 29.7d^2\sqrt{P}$

(1) $GPM = (29.7)(2)^2 \sqrt{95}$

(2) GPM = 29.7 X 4 X 9.7467943

(3) GPM = 1,157.9191

5. Find GPM flow from 1 7/8" tip at 75 PSI

a. $GPM = 29.7d^2 \sqrt{P}$

(1) $GPM = (29.7)(1.875)^2\sqrt{75}$

(2) GPM = 29.7 X 3.515625 X 8.660254

(3) GPM = 904.25228

6. Find GPM discharge from 2 1/2" port at 50 PSI

a. $GPM = 29.7d^2\sqrt{P}$

(1) $GPM = (29.7)(2.5)^2 \sqrt{50}$

(2) GPM = 29.7 X 6.25 X 7.0710678

(3) GPM = 1,312.5669

7. Find GPM discharge from 5" steamer port at 22 PSI

a. $GPM = 29.7d^2\sqrt{P}$

(1) $GPM = (29.7)(5)^2 \sqrt{22}$

(2) GPM = 29.7 X 25 X 4.6904157

(3) GPM = 3482.6335

D. Friction Loss (In PSI)

SM Pg 7

NOTE

THE MOST ACCURATE METHOD OF DETERMINING FRICTION LOSS FOR A PARTICULAR SIZE AND TYPE OF HOSE IS THROUGH ACTUAL FIELD TESTS, MEASURING FRICTION LOSS AT VARIOUS FLOWS. SINCE THIS IS NOT PRACTICAL FOR THOSE OF US WHO UTILIZE A NUMBER OF DIFFERENT HOSES (i.e. manufacturer, age, type of construction), FRICTION LOSS FORMULAS PROVIDE AN ESTIMATED FRICTION LOSS WHICH ALLOWS US TO FUNCTION ON THE FIRE GROUND.

1. Formula to calculate friction loss in fire hose:

OHT #H36

a. $FL = CQ^2L$

(1) **FL** is friction loss in psi

(2) **C** is friction loss coefficient

(3) **Q** is GPM flow divided by 100

(a) Q = GPM ÷ 100

(4) **L** is hose length divided by 100

(a) L = Hose Length ÷ 100

FRICTION LOSS COEFFICIENTS - SINGLE LINE	
Hose Diameter (in inches)	**Coefficient (C)**
3/4” Booster	1100.00
1” Booster	150.00
1 1/2”	24.00
1 3/4”	15.50
2 1/2”	2.00
3”	0.80
3 1/2”	0.34
4”	0.20
4 1/2”	0.10
5”	0.08
6”	0.05

FRICTION LOSS COEFFICIENTS - SIAMESED LINES OF EQUAL LENGTH	
Hose Diameter (in inches)	**Coefficient (C)**
Two 2 1/2”	0.50
Three 2 1/2”	0.22
One 3” & one 2 1/2”	0.30
Two 3”	0.20
Two 2 1/2” & One 3”	0.16
Two 3” & One 2 1/2”	0.12

INSTRUCTOR NOTE

THE FOLLOWING EXAMPLES AND PROBLEMS WERE RANDOMLY DEVELOPED. SPECIFIC PROBLEMS SHOULD BE GENERATED FOR EACH PARTICIPATING DEPARTMENTS PRECONNECT HOSE LINES AND HOSE LAYS. THIS WILL HELP KEEP THE ATTENTION OF ALL STUDENTS.

OHT #H37

2. Find friction loss in 100' of 2 1/2" flowing 500 GPM (student manual example)

a. C = Friction Loss Coefficient for 2 1/2" hose

(1) C = 2

b. Q = GPM ÷ 100

(1) Q = 500 ÷ 100

(2) Q = 5

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c. L = Hose Length ÷ 100

(1) L = 100 ÷ 100

(2) L = 1

d. $FL = CQ^2L$

(1) $FL = (2)(5)^2(1)$

(2) FL = 2 x 25 x 1

(3) FL = 50 x 1

(4) FL = 50 PSI

3. Find friction loss in 500' of 2 1/2" hose flowing 300 GPM (student manual example)

OHT #H38

a. C = Friction Loss Coefficient for 2 1/2" hose

(1) C = 2

b. Q = GPM ÷ 100

(1) Q = 300 ÷ 100

(2) Q = 3

c. L = Hose Length ÷ 100

(1) L = 500 ÷ 100

(2) L = 5

d. $FL = CQ^2L$

(1) $FL = (2)(3)^2(5)$

(2) FL = 2 x 9 x 5

(3) FL = 18 x 5

(4) FL = 90 PSI

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4. Find friction loss in 100' of 1 3/4" flowing 200 GPM (student manual example)

OHT #H39

a. C = Friction Loss Coefficient for 1 3/4"

(1) C = 15.5

b. Q = GPM ÷ 100

(1) Q = 200 ÷ 100

(2) Q = 2

c. L = Hose Length ÷ 100

(1) L = 100 ÷ 100

(2) L = 1

d. $FL = CQ^2L$

(1) $FL = (15.5)(2)^2(1)$

(2) FL = 15.5 x 4 x 1

(3) FL = 62 x 1

(4) FL = 62 PSI

5. Find friction loss in 500' of 3" flowing 500 GPM (student manual example)

OHT #H40

a. C = Friction Loss Coefficient for 3"

(1) C = .8

b. Q = GPM ÷ 100

(1) Q = 500 ÷ 100

(2) Q = 5

c. L = Hose Length ÷ 100

(1) L = 500 ÷ 100

(2) L = 5

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d. $FL = CQ^2L$

(1) $FL = (.8)(5)^2(5)$

(2) FL = .8 x 25 x 5

(3) FL = 20 x 5

(4) FL = 100 PSI

6. Find friction loss in 150' of 1 1/2" flowing 60 GPM (student manual example)

OHT #H41

a. C = Friction Loss Coefficient for 1 1/2" hose

(2) C = 24

b. Q = GPM ÷ 100

(1) Q = 60 ÷ 100

(2) Q = .6

c. L = Hose Length ÷ 100

(1) L = 150 ÷ 100

(2) L = 1.5

d. $FL = CQ^2L$

(1) $FL = (24)(.6)^2(1.5)$

(2) FL = 24 x .36 x 1.5

(3) FL = 8.64 x 1.5

(4) FL = 12.96 PSI

7. Find friction loss in 500' of double 3" lines flowing 1000 GPM (student manual example)

OHT #H42

a. C = Friction Loss Coefficient for double 3" lines

(1) C = .2

b. Q = GPM ÷ 100

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(1) Q = 1000 ÷ 100

(2) Q = 10

c. L = Hose Length ÷ 100

(1) L = 500 ÷ 100

(2) L = 5

d. $FL = CQ^2L$

(1) $FL = (.2)(10)^2(5)$

(2) FL = .2 x 100 x 5

(3) FL = 20 x 5

(4) FL = 100 PSI

8. Find friction loss in 1000' of 5" flowing 1000 GPM

OHT #H43

a. C = Friction Loss Coefficient for 5" hose

(1) C = .08

b. Q = GPM ÷ 100

(1) Q = 1000 ÷ 100

(2) Q = 10

c. L = Hose Length ÷ 100

(1) L = 1000 ÷ 100

(2) L = 10

d. $FL = CQ^2L$

(1) $FL = (.08)(10)^2(10)$

(2) FL = .08 x 100 x 10

(3) FL = 8 x 10

(4) FL = 80 PSI

9. Find friction loss in 150' of 1 1/2" flowing 125 GPM

a. C = Friction Loss Coefficient for 1 1/2" hose

(1) C = 24

b. Q = GPM ÷ 100

(1) Q = 125 ÷ 100

(2) Q = 1.25

c. L = Hose Length ÷ 100

(1) L = 150 ÷ 100

(2) L = 1.5

d. $FL = CQ^2L$

(1) $FL = (24)(1.25)^2 1.5$

(2) FL = 24 x 1.5625 x 1.5

(3) FL = 37.5 x 1.5

(4) FL = 56.25 PSI

10. Find friction loss in 750' of one 3 and one 2 1/2" hose flowing 750 GPM

a. C = Friction Loss Coefficient for one 3" and one 2 1/2" hose

(1) C = .3

b. Q = GPM ÷ 100

(1) Q = 750 ÷ 100

(2) Q = 7.5

c. L = Hose Length ÷ 100

(1) L = 750 ÷ 100

(2) L = 7.5

d. $FL = CQ^2L$

(1) $FL = (.3)(7.5)^2(7.5)$

(2) FL = .3 x 56.25 x 7.5

(3) FL = 16.875 x 7.5

(4) FL = 126.5625 PSI

11. Find friction loss in 200' of 3/4" booster hose flowing 20 GPM

a. C = Friction Loss Coefficient for 3/4" booster hose

(1) C = 1100

b. Q = GPM ÷ 100

(1) Q = 20 ÷ 100

(2) Q = .2

c. L = Hose Length ÷ 100

(1) L = 200 ÷ 100

(2) L = 2

d. $FL = CQ^2L$

(1) $FL = (1100)(.2)^2(2)$

(2) $FL = 1100 \times .04 \times 2$

(3) $FL = 44 \times 2$

(4) $FL = 88$ PSI

12. Find friction loss in 1200' of one 3” and one 2 1/2" flowing 1000 GPM

a. C = Friction Loss Coefficient for one 3” and one 2 1/2"

(1) C = .3

b. Q = GPM ÷ 100

(1) Q = 1000 ÷ 100

(2) Q = 10

c. L = Hose Length ÷ 100

(1) L = 1200 ÷ 100

(2) L = 12

d. $FL = CQ^2L$

(1) $FL = (.3)(10)^2(12)$

(2) $FL = .3 \times 100 \times 12$

(3) $FL = 30 \times 12$

(4) FL = 360 PSI

13. Find friction loss in 700' of one 3” and one 2 1/2" flowing 1000 GPM

a. C = Friction Loss Coefficient for one 3" and one 2 1/2"

(1) C = .3

b. Q = GPM ÷ 100

(1) Q = 1000 ÷ 100

(2) Q = 10

c. L = Hose Length ÷ 100

(1) L = 700 ÷ 100

(2) L = 7

d. $FL = CQ^2L$

(1) $FL = (.3)(10)^2(7)$

(2) FL = .3 x 100 x 7

(3) FL = 30 x 7

(4) FL = 210 PSI

14. Find friction loss in 1000' of two 3" and one 2 1/2" flowing 1200 GPM

a. C = Friction Loss Coefficient for two 3" and one 2 1/2"

(1) C = .12

b. Q = GPM ÷ 100

(1) Q = 1200 ÷ 100

(2) Q = 12

c. L = Hose Length ÷ 100

(1) L = 1000 ÷ 100

(2) L = 10

d. $FL = CQ^2L$

(1) FL = (.12)(12)²(10)

(2) FL = .12 x 144 x 10

(3) FL = 17.28 x 10

(4) FL = 172.8 PSI

E. Pump Discharge Pressure (In PSI)

SM Pg 12

1. Formula for finding required Pump Discharge Pressure (PDP) is:

OHT #H44

a. PDP = NP + FL

(1) **PDP** is pump discharge pressure

(2) **NP** is nozzle pressure

NOTE

FOG NOZZLES ARE DESIGNED TO OPERATE AND DELIVER RATED GALLONAGES AT 100 PSI. ALWAYS USE 100 PSI NOZZLE PRESSURE TO CALCULATE PUMP DISCHARGE PRESSURE WHEN UTILIZING FOG NOZZLES.

(3) **FL** is friction loss

2. Find pump discharge pressure required for supplying 200' of 2 1/2" hose equipped with 200 GPM fog nozzle operating at 100 PSI nozzle pressure (student manual example)

OHT #H45

a. C = Friction Loss Coefficient for 2 1/2" hose

(1) C = 2

b. Q = GPM ÷ 100

(1) Q = 200 ÷ 100

(2) Q = 2

c. L = Hose Length ÷ 100

(1) L = 200 ÷ 100

(2) L = 2

d. $FL = CQ^2L$

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

(2) FL = 2 x 4 x 2

(3) FL = 8 x 2

(4) FL = 16 PSI

e. PDP = NP + FL

(1) PDP = 100 + 16

(2) PDP = 116 PSI

SM Pg 13

3. Find pump discharge pressure required for supplying 200' of 1 3/4" hose equipped with 200 GPM automatic fog nozzle (student manual example)

a. C = Friction Loss Coefficient for 1 3/4" hose

(1) C = 15.5

b. Q = GPM ÷ 100

(1) Q = 200 ÷ 100

(2) Q = 2

c. L = Hose Length ÷ 100

(1) L = 200 ÷ 100

(2) L = 2

d. $FL = CQ^2L$

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

(2) FL = 15.5 x 4 x 2

(3) FL = 62 x 2

(4) FL = 124 PSI

e. PDP = NP + FL

(1) PDP = 100 + 124

(2) PDP = 224 PSI

4. Find pump discharge pressure required for supplying 200' of 2 1/2" hose equipped with 350 GPM fog nozzle operating at 100 PSI nozzle pressure

a. C = Friction Loss Coefficient for 2 1/2" hose

(1) C = 2

b. Q = GPM ÷ 100

(1) Q = 350 ÷ 100

(2) Q = 3.5

c. L = Hose Length ÷ 100

(1) L = 200 ÷ 100

(2) L = 2

d. $FL = CQ^2L$

(1) $FL = (2)(3.5)^2(2)$

(2) FL = 2 x 12.25 x 2

(3) FL = 24.5 x 2

(4) FL = 49 PSI

e. PDP = NP + FL

(1) PDP = 100 + 49

(2) PDP = 149 PSI

5. Find pump discharge pressure required for supplying 200' of 1 3/4" hose equipped with 350 GPM automatic fog nozzle

a. C = Friction Loss Coefficient for 1 3/4" hose

(1) C = 15.5

b. Q = GPM ÷ 100

(1) Q = 350 ÷ 100

(2) Q = 3.5

c. L = Hose Length ÷ 100

(1) L = 200 ÷ 100

(2) L = 2

d. $FL = CQ^2L$

(1) $FL = (15.5)(3.5)^2(2)$

(2) FL = 15.5 x 12.25 x 2

(3) FL = 189.875 x 2

(4) FL = 379.75 PSI

e. PDP = NP + FL

(1) PDP = 100 + 379.75

(2) PDP = 479.75 PSI

III. MENTAL FORMULAS - RULES OF THUMB

SM Pg 14

A. Fireground activities often prohibit use of formulas because of:

1. Existing conditions

2. Lack of time

B. Rules of thumb can be used when necessary to calculate quickly

C. There are several rules of thumb used for quick calculations

OHT #H46

1. Most common are:

   a. Condensed "Q"

   b. Counting fingers

      (1) five finger method

   c. Gallons flowing

2. Order of presentation in no way signifies their value or importance

3. Adaptation must be made:

   a. By local jurisdictions

   b. To best advantage of all concerned

D. Condensed "Q"

1. 3" hose is used to supply master streams

   a. Beneficial due to reduction of friction loss

OHT #47

2. Friction loss per 100' of 3" hose determined by:

   a. $FL = Q^2$

      (1) $Q = GPM \div 100$

3. Not as accurate as conversion factor from the table, but:

   a. More rapid

   b. Sufficiently accurate for fireground operations

4. For practical purposes, 3" hose with either 3" or 2 1/2" couplings can be treated identically

5. Using condensed Q formula:

a. Find friction loss per 100' of 3" hose flowing 200 GPM

OHT #H48

(1) Q = GPM ÷ 100

(a) Q = 200 ÷ 100

(b) Q = 2

(2) FL = Q^2

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

(b) FL = 2 x 2

(c) FL = 4 PSI / 100'

b. Find friction loss per 100' of 3" hose flowing 500 GPM

(1) Q = GPM ÷ 100

(a) Q = 500 ÷ 100

(b) Q = 5

(2) FL = Q^2

(a) FL = $(5)^2$

(b) FL = 5 X 5

(c) FL = 25 PSI / 100'

c. Find pump discharge pressure needed to supply 500 GPM master fog stream with 600' lay of 3" hose

(1) Q = GPM ÷ 100

(a) Q = 500 ÷ 100

(b) Q = 5

(2) $FL = Q^2$

(a) $FL = (5)^2$

(b) FL = 5 X 5

(c) FL = 25 PSI / 100'

(3) Total FL = 25 X 6

(4) Total FL = 150 PSI

(5) PDP = NP + FL

(a) PDP = 100 + 150

(b) PDP = 250 PSI

E. Counting Fingers - Five Finger Method

1. Uses hand and fingers

a. Applies only to:

(1) 2 1/2" hose

(2) flowing 100 - 500 GPM

OHT #H49

2. Starting with thumb of left hand:

a. Each finger is numbered at tip in terms of "Q" or GPM ÷ 100

(1) thumb is 1

(2) index is 2

(3) middle is 3

(4) ring is 4

(5) little is 5

b. Base of each finger is given a successive even number, beginning with two

(1) thumb is 2

(2) index is 4

(3) middle is 6

(4) ring is 8

(5) little is 10

3. Friction loss for 100' of 2 1/2" hose at desired flow is determined by:

a. Selecting finger to which desired flow has been assigned

OHT #H50

(1) multiplying number at tip of finger by number at the base of finger

4. Friction loss for 500 GPM flow can be found by using the numbers assigned to little finger

SM Pg 15

a. FL = 5 X 10

b. FL = 50 PSI / 100' of 2 1/2" hose

5. Friction loss for 200 GPM flow is found by using the numbers assigned to the index finger

a. FL = 2 X 4

b. FL = 8 PSI / 100' of 2 1/2" hose

6. Since nozzle capacities vary in GPM, nearest half-hundreds of flow can be used with slight variations

OHT #H51

a. "Q" for half-hundred flows can be assigned to spaces between fingers

(1) between thumb and index is 1.5

(2) between index and middle is 2.5

(3) between middle and ring is 3.5

(4) between ring and little is 4.5

b. Base of each finger space is given a successive odd number, starting with three

(1) between thumb and index is 3

(2) between index and middle is 5

(3) between middle and ring is 7

(4) between ring and little is 9

OHT #H52

7. Counting finger method can also be used for 3" hose

OHT #H53

a. Number base of fingers with:

(1) 1

(2) 2

(3) 3

(4) 4

(5) 5

b. Flows through 3" hose must be rounded to nearest hundred

c. Gives same results as:

(1) Condensed "Q"

8. Using finger counting method:

a. Find friction loss per 100' of 2 1/2" hose flowing 300 GPM

(1) FL = 3 X 6

(2) FL = 18 PSI / 100'

b. Find friction loss per 100' of 2 1/2" hose flowing 500 GPM

(1) FL = 5 X 10

(2) FL = 50 PSI / 100'

c. Find friction loss per 100' of 2 1/2" hose flowing 150 GPM

(1) FL = 1.5 X 3

(2) FL = 4.5 PSI / 100'

d. Find friction loss per 100' of 3" hose flowing 400 GPM

(1) FL = 4 X 4

(2) FL = 16 PSI / 100'

e. Find friction loss per 100' of 3" hose flowing 200 GPM

(1) FL = 2 X 2

(2) FL = 4 PSI / 100'

f. Find total friction loss in 500' line of 2 1/2" hose flowing 400 GPM

(1) FL = 4 X 8

(2) FL = 32 PSI / 100'

(3) Total FL = 32 X 5

(4) Total FL = 160 PSI

g. Find total friction loss in 600' line of 3" hose flowing 300 GPM

(1) FL = 3 X 3

(2) FL = 9 PSI / 100'

(3) Total FL = 9 X 6

(4) Total FL = 54 PSI

h. Find total friction loss in 400' line of 2 1/2" hose flowing 450 GPM

(1) FL = 4.5 X 9

(2) FL = 40.5 PSI / 100'

(3) Total FL = 40.5 X 4

(4) Total FL = 162 PSI

i. Determine needed pump discharge pressure to supply 500 GPM master fog stream through 3" line 400' in length

(1) FL = 5 X 5

(2) FL = 25 PSI / 100'

(3) Total FL = 25 X 4

(4) Total FL = 100

(5) PDP = 100 + 100

(6) PDP = 200 PSI

j. Determine needed pump discharge pressure to supply 250 GPM fog nozzle through 300' of 2 1/2" hose

(1) FL = 2.5 X 5

(2) FL = 12.5 PSI / 100'

(3) Total FL = 12.5 X 3

(4) Total FL = 37.5 PSI

(5) PDP = 100 + 37.5

(6) PDP = 137.5 PSI

APPLICATION: Have class define:

1. Atmospheric Pressure

2. Capacity
3. Displacement
4. Flow (GPM)
5. Flow Pressure
6. Friction Loss
7. Head Pressure
8. Hydrant Pressure
9. Negative Pressure
10. Net Engine Pressure
11. Normal Operating Pressure
12. Nozzle Reaction
13. Pounds Per Square Inch (PSI)
14. Pump Discharge Pressure
15. Residual Pressure
16. Static Pressure
17. Vacuum
18. Velocity
19. Water Hammer

Ask class to give the formulas for calculating:

1. Area of Circle
2. Capacity of Cylinder (In Gallons)
3. Water Flow (In GPM)
4. Friction Loss (In PSI)
5. Pump Discharge Pressure (In PSI)

Ask the class questions requiring them to utilize the rule-of-thumb method for finding friction loss.

SUMMARY: We have covered definitions of words and phrases used in hydraulics. Some of these, used in a different context, wouldn't have the same meaning, so it will be important for you to remember these as defined. The written formulas we worked on are necessary for a basic understanding of how friction loss is calculated, so the rule-of-thumb methods can be better understood. Does anyone have any questions or comments?

CONCLUSION: & ASSIGNMENT: If there are no further questions, I will hand out a written test for you to complete. A score of 70% is needed to pass the test and receive credit for the class.

DRILL GROUND PREPARATIONS
PUMPER OPERATOR HYDRAULICS (Part I) PRACTICAL EXERCISES

Materials Needed:

1. One (1) engine with operator
2. Supply Lines (2 1/2" and/or 3")
3. Fire Hydrant (output should exceed capacity of pump)
4. Discharge Lines (hand lines and master stream lines)
5. Master Stream Device(s) with straight tips and adjustable fog nozzles
6. Flow Test Kit
7. In-lines Gauges (1 1/2" & 2 1/2" • 0# - 300#)

Station 1: Engine connected to hydrant with 250' double lay of supply line, using one 2 1/2" and one 3". (Another 2 1/2" may be substituted for the 3". If a double lay of 3" is used, the supply line length may need to be increased.) Place at least one in-line gauge in each line. (Use more if available)

Connect master stream device to engine with a double lay of 2 1/2" hose. Place flow test unit on master stream. (Put in appropriate nozzle for flow) Place at least one in-line gauge in each line. (Use more if available)

Connect a 2 1/2" handline to the engine. (100' long with at least a 250 GPM nozzle) Place an in-line gauge between hose and nozzle.

Connect a 1 1/2" or 1 3/4" handline to the engine. (200' long with at least a 100 GPM nozzle) Place in-line gauge between hose and nozzle. (Use another at 100' hose connection, if available)

NOTE: ENGINE SUPPLY LINES SHOULD NEVER BE ABLE TO PROVIDE ENOUGH WATER FOR PUMP TO PERFORM AT CAPACITY. IT IS IMPORTANT FOR STUDENTS TO UNDERSTAND THAT JUST BECAUSE THEY HAVE A HYDRANT THAT WILL PRODUCE 1000 GPM AND AN ENGINE WITH A RATED PUMP CAPACITY OF 1000 GPM, THAT DOES NOT MEAN THEY WILL BE ABLE TO DELIVER 1000 GPM WHEN LOCATED EVEN A MINIMAL DISTANCE FROM THE HYDRANT. SO IF LARGER SUPPLY LINES ARE USED, INCREASE THEIR LENGTH SO AS TO PROVIDE NO MORE THAN 90% OF RATED PUMP CAPACITY.

DISCHARGE LINES MAY BE ADJUSTED TO FIT INDIVIDUAL REQUIREMENTS.

Using one 2 1/2" supply line and the 1 1/2" or 1 3/4" handline, have students correctly calculate the friction loss in the supply line and the discharge line based on nozzle

discharge at 100 psi. Then flow hose and read pressure gauges to see if calculations were correct. If connected with a 2 1/2" and a 3" supply line, make same calculations using only the 3" line. Follow same procedures.

Using one 2 1/2" supply line and the 2 1/2" handline, have the students correctly calculate the friction loss in the supply line and the discharge line based on nozzle discharge at 100 psi. Then flow hose and read pressure gauges to see if calculations were correct. If connected with a 2 1/2" and a 3" supply line, make same calculations using only the 3" line. Follow same procedures.

Using one 2 1/2" supply line and the master stream device, have students correctly calculate the friction loss in the supply line and the discharge line based on a specified discharge. Then flow hose and read pressure gauges to see if calculations were correct. If connected with a 2 1/2" and a 3" supply line, make same calculations using only the 3" line. Follow same procedures. Then use both supply lines to provide same quantity of water and have students calculate friction loss accordingly. Gradually increase flows until residual pressure at the pump is 20 psi.

NOTE: ASK STUDENTS WHY THE ENGINE WILL NOT PRODUCE ITS CAPACITY. MAKE SURE THEY ALL REALIZE IT IS THE SUPPLY LINES THAT LIMIT THE AMOUNT OF WATER A SPECIFIC COMBINATION OF HYDRANT AND ENGINE WILL PRODUCE.

Intent: 1. To demonstrate the impact friction loss has on pumping operations.

NAME:_____ **DATE:**_____

HYDRAULICS I EVALUATION

Put the number of the word on the line next to phrase which best defines how it applies to hydraulics.

A. Atmospheric Pressure
B. Capacity
C. Displacement
D. Flow (GPM)
E. Flow Pressure
F. Friction Loss
G. Head Pressure
H. Hydrant Pressure
I. Negative Pressure
J. Net Engine Pressure
K. Normal Operating Pressure
L. Nozzle Reaction
M. Pounds Per Square Inch (PSI)
N. Pump Discharge Pressure
O. Residual Pressure
P. Static Pressure
Q. Vacuum
R. Velocity
S. Water Hammer

1. _____ The motion characteristics of water; as defined for this class it is the quantity of water moving, measured in gallons per minute.

2. _____ That part of the total pressure not used to overcome friction or gravity while forcing water through fire hose, pipe, fittings, and adapters.

3. _____ The amount of water drawn into the pump - displacing the air.

4. _____ Speed; the rate of motion in a given direction. As defined for this class, it is the speed of water as it leaves the orifice, measured in PSI.

5. _____ That pressure exerted by a stationary column of water, directly proportional to the height of the column.

6. _____ Any pressure less than atmospheric pressure.

7. _____ The counterforce directed against the people or device holding a nozzle by the velocity of water being discharged.

8. _____ Stored or potential energy that is available to force water through pipes and fittings, fire hose, and adapters.

9. _____ A force created by the deceleration or acceleration of water.

10. _____ The pressure exerted by the atmosphere at the surface of the earth due to the weight of air.

11. _____ That pressure found in a water distribution system during normal consumption demands.

12. _____ Unit of measure; as defined for this class, it is the pressure or velocity exerted by a liquid per square inch of surface area.

13. _____ The total amount of pressure being discharged by a pump.

14. _____ That part of the total pressure lost as water moves through a hose or piping system, caused by water turbulence and the roughness of interior surfaces of hose or pipe.

15. _____ The amount of pressure actually being created by the pump.

16. _____ The maximum ability of a pump or water distribution system to deliver water.

17. _____ Pressure created by the rate of flow or velocity of water coming from a discharge opening.

18. _____ The amount of pressure being supplied by a hydrant without assistance.

19. _____ Any pressure less than normal operating pressure.

20. Find the area of a nozzle 2 1/4" in diameter.

$A = \pi r^2$ or $A = \pi d^2 \div 4$

21. Find the capacity in gallons of a swimming pool 30' in diameter and 5' deep.

$Gal = d^2 6L$ or Cu. Ft. (ft^3) = $\pi r^2 L$ ❖ Gal = ft^3 x 7.48

22. Find the GPM flow through a 2 1/4" nozzle at 64 PSI.

$GPM = 29.7d^2\sqrt{P}$

$FL = CQ^2L$

23. Find the friction loss per 100' of 2 1/2" hose flowing 450 GPM.

24. Find the pump discharge pressure required to supply a 500 GPM master stream fog nozzle using 400' of 2 1/2" hose.

25. Find the required pump discharge pressure to supply a 350 GPM automatic fog nozzle using 150' of 1 3/4" hose.

26. Find the required nozzle pressure to supply a 350 GPM automatic fog nozzle using 150' of 2 1/2" hose.

27. Calculate the friction loss in 900' of one 3" and one 2 1/2" flowing 750 GPM.

28. Calculate the friction loss in 400' of one 3" and one 2 1/2" flowing 1200 GPM.

29. Calculate the friction loss in 600' of one 3" and one 2 1/2" flowing 1500 GPM.

30. Calculate the friction loss in 1200’ of 5” hose flowing 1000 GPM.

FRICTION LOSS COEFFICIENTS - SINGLE LINE	
Hose Diameter (in inches)	**Coefficient (C)**
3/4” Booster	1100.00
1” Booster	150.00
1 1/2”	24.00
1 3/4”	15.50
2 1/2”	2.00
3”	0.80
3 1/2”	0.34
4”	0.20
4 1/2”	0.10
5”	0.08
6”	0.05

FRICTION LOSS COEFFICIENTS - SIAMESED LINES OF EQUAL LENGTH	
Hose Diameter (in inches)	**Coefficient (C)**
Two 2 1/2”	0.50
Three 2 1/2”	0.22
One 3” & one 2 1/2”	0.30
Two 3”	0.20
Two 2 1/2” & One 3”	0.16
Two 3” & One 2 1/2”	0.12

ANSWER KEY

HYDRAULICS I EVALUATION

Put the number of the word on the line next to phrase which best defines how it applies to hydraulics.

A. Atmospheric Pressure
B. Capacity
C. Displacement
D. Flow (GPM)
E. Flow Pressure
F. Friction Loss
G. Head Pressure
H. Hydrant Pressure
I. Negative Pressure
J. Net Engine Pressure
K. Normal Operating Pressure
L. Nozzle Reaction
M. Pounds Per Square Inch (PSI)
N. Pump Discharge Pressure
O. Residual Pressure
P. Static Pressure
Q. Vacuum
R. Velocity
S. Water Hammer

1. ***D*** The motion characteristics of water; as defined for this class it is the quantity of water moving, measured in gallons per minute.

2. ***O*** That part of the total pressure not used to overcome friction or gravity while forcing water through fire hose, pipe, fittings, and adapters.

3. ***C*** The amount of water drawn into the pump - displacing the air.

4. ***R*** Speed; the rate of motion in a given direction. As defined for this class, it is the speed of water as it leaves the orifice, measured in PSI.

5. ***G*** That pressure exerted by a stationary column of water, directly proportional to the height of the column.

6. ***Q*** Any pressure less than atmospheric pressure.

7. ***L*** The counterforce directed against the people or device holding a nozzle by the velocity of water being discharged.

8. ***P*** Stored or potential energy that is available to force water through pipes and fittings, fire hose, and adapters.

9. ***S*** A force created by the deceleration or acceleration of water.

10. ***A*** The pressure exerted by the atmosphere at the surface of the earth due to the weight of air.

11. ***K*** That pressure found in a water distribution system during normal consumption demands.

12. ***M*** Unit of measure; as defined for this class, it is the pressure or velocity exerted by a liquid per square inch of surface area.

13. ***N*** The total amount of pressure being discharged by a pump.

14. ***F*** That part of the total pressure lost as water moves through a hose or piping system, caused by water turbulence and the roughness of interior surfaces of hose or pipe.

15. ***J*** The amount of pressure actually being created by the pump.

16. ***B*** The maximum ability of a pump or water distribution system to deliver water.

17. ***E*** Pressure created by the rate of flow or velocity of water coming from a discharge opening.

18. ***H*** The amount of pressure being supplied by a hydrant without assistance.

19. ***I*** Any pressure less than normal operating pressure.

20. Find the area of a nozzle 2 1/4" in diameter.

$A = \pi r^2$ or $A = \pi d^2 \div 4$

$A = (3.14)(1.125)^2$
$A = 3.14 \times 1.265625$
A = 3.9740625 sq. in.

$A = (3.14)(2.25)^2 \div 4$
$A = 3.14 \times 5.0625 \div 4$
$A = 15.89625 \div 4$
A = 3.9740625 sq. in.

21. Find the capacity in gallons of a swimming pool 30' in diameter and 5' deep.

$Gal = d^2 6L$ or $\text{Cu. Ft. } (ft^3) = \pi r^2 L$
$Gal = ft^3 \times 7.48$

$Gal = (30)^2(6)(5)$
$Gal = 900 \times 6 \times 5$
Gal = 27,000 (approx.)

$\text{Cu. Ft.} = (3.14)(15)^2(5)$
$\text{Cu. Ft.} = 3.14 \times 225 \times 5$
$\text{Cu. Ft.} = 3532.5$

$Gal = 3532.5 \times 7.48$
Gal = 26423.1 (exact)

22. Find the GPM flow through a 2 1/4" nozzle at 64 PSI.

$GPM = 29.7d^2\sqrt{P}$
$GPM = (29.7)(2.25)^2 \sqrt{64}$
$GPM = 29.7 \times 5.0625 \times 8$
GPM = 1202.85

$FL = CQ^2L$

23. Find the friction loss per 100' of 2 1/2" hose flowing 450 GPM.

    $FL = (2)(4.5)^2(1)$
    $FL = 2 \times 20.25 \times 1$
    FL = 40.5 PSI

24. Find the pump discharge pressure required to supply a 500 GPM master stream fog nozzle using 400' of 2 1/2" hose.

    $FL = (2)(5)^2(4)$ PDP = FL + NP
    $FL = 2 \times 25 \times 4$ PDP = 200 + 100
    FL = 200 PSI ***PDP = 300 PSI***

25. Find the required pump discharge pressure to supply a 350 GPM automatic fog nozzle using 150' of 1 3/4" hose.

    $FL = (15.5)(3.5)^2(1.5)$ PDP = FL + NP
    $FL = 15.5 \times 12.25 \times 1.5$ PDP = 284.8125 + 100
    FL = 284.8125 PSI ***PDP = 384.8125 PSI***

26. Find the required nozzle pressure to supply a 350 GPM automatic fog nozzle using 150' of 2 1/2" hose.

    Required Nozzle Pressure = 100 PSI

27. Calculate the friction loss in 900' of one 3" and one 2 1/2" flowing 750 GPM.

    $FL = (.3)(7.5)^2(9)$
    $FL = .3 \times 56.25 \times 9$
    FL = 151.875 PSI

28. Calculate the friction loss in 400' of one 3" and one 2 1/2" flowing 1200 GPM.

    $FL = (.3)(12)^2(4)$
    $FL = .3 \times 144 \times 4$
    FL = 172.8 PSI

29. Calculate the friction loss in 600' of one 3" and one 2 1/2" flowing 1500 GPM.

    $FL = (.3)(15)^2(6)$
    $FL = .3 \times 225 \times 6$
    FL = 405 PSI

30. Calculate the friction loss in 1200’ of 5” hose flowing 1000 GPM.

    $FL = (.08)(10)^2(12)$
    $FL = .08 \times 100 \times 12$

FL = 96 PSI

FRICTION LOSS COEFFICIENTS - SINGLE LINE	
Hose Diameter (in inches)	**Coefficient (C)**
3/4” Booster	1100.00
1” Booster	150.00
1 1/2”	24.00
1 3/4”	15.50
2 1/2”	2.00
3”	0.80
3 1/2”	0.34
4”	0.20
4 1/2”	0.10
5”	0.08
6”	0.05

FRICTION LOSS COEFFICIENTS - SIAMESED LINES OF EQUAL LENGTH	
Hose Diameter (in inches)	**Coefficient (C)**
Two 2 1/2”	0.50
Three 2 1/2”	0.22
One 3” & One 2 1/2”	0.30
Two 3”	0.20
Two 2 1/2” & One 3”	0.16
Two 3” & One 2 1/2”	0.12

STUDENT MANUAL
HYDRAULICS (Part I)

STANDARD: NFPA 1002 (1998 Edition)

REFERENCE: IFSTA "Fire Stream Practices", 7th Edition
IFSTA "Pumping Apparatus", 7th Edition
IFSTA "Water Supplies", 4th Edition
Fire Service Hydraulics, 2nd Edition

OBJECTIVES: At the end of this class the apparatus operator shall:

1. Define the following terms as they relate to fire service hydraulics:
   a. Atmospheric Pressure
   b. Capacity
   c. Displacement
   d. Flow (GPM)
   e. Flow Pressure
   f. Friction Loss (FL)
   g. Head Pressure
   h. Hydrant Pressure
   i. Negative Pressure
   j. Net Engine Pressure
   k. Normal Operating Pressure
   l. Nozzle Reaction
   m. Pounds Per Square Inch (PSI)
   n. Pump Discharge Pressure (PDP)
   o. Residual Pressure
   p. Static Pressure
   q. Vacuum
   r. Velocity
   s. Water Hammer
2. Determine the following:
   a. Friction loss in siamesed lines when the size of hose and gpm flow are given
   b. Nozzle or pump discharge pressures when the length and size of hose and size of nozzle are given
   c. Friction loss in the supply and attack lines (used by the department) when the gpm flow is given
   d. Water flow in gallons per minute when the diameter of the orifice and pressure at the orifice are given

FIRE SERVICE HYDRAULICS
TERMINOLOGY & DEFINITIONS

ATMOSPHERIC PRESSURE:
The pressure exerted by the atmosphere at the surface of the earth due to the weight of air. ***NOTE:*** *Atmospheric pressure at sea level is about 14.7 psi. It increases as elevation decreases below sea level and decreases as elevation increases above sea level.*

CAPACITY:
The maximum ability of a pump or water distribution system to deliver water.

DISPLACEMENT:
The amount of water drawn into the pump - displacing the air.

FLOW (GPM):
The motion characteristics of water; as defined for this class it is the quantity of water moving, measured in gallons per minute.

FLOW PRESSURE:
Pressure created by the rate of flow or velocity of water coming from a discharge opening. ***NOTE:*** *Flow pressure is measured in Pounds Per Square Inch (PSI).*

FRICTION LOSS (PRESSURE LOSS DUE TO FRICTION):
That part of the total pressure lost as water moves through a hose or piping system, caused by water turbulence and the roughness of interior surfaces of hose or pipe.

HEAD PRESSURE:
That pressure exerted by a stationary column of water, directly proportional to the height of the column. ***NOTE:*** *A column of water 2.304 feet high will create one (1) psi of pressure at the base. A column of water one (1) foot high will create .434 psi of pressure at the base.*

HYDRANT PRESSURE:
The amount of pressure being supplied by a hydrant without assistance.

NEGATIVE PRESSURE:
Any pressure less than normal operating pressure. ***NOTE:*** *We create a negative pressure every time we open a fire hydrant.*

NET ENGINE PRESSURE:
The amount of pressure actually being created by the pump. ***NOTE:*** *In mathematical terms, it is the Pump Discharge Pressure minus the Pump Intake Pressure.*

(PDP - PIP = NEP)

NORMAL OPERATING PRESSURE:
That pressure found in a water distribution system during normal consumption demands.

NOZZLE REACTION:
The counterforce directed against the people or device holding a nozzle by the velocity of water being discharged. ***NOTE:*** *The backward thrust of the water, at the nozzle, is equal to the discharge velocity and flow, or the forward movement of the nozzle when discharge velocity and flow are decreased.*

POUNDS PER SQUARE INCH (PSI):
Unit of measure; as defined for this class, it is the pressure exerted by a liquid per square inch of surface area or as a measure of velocity.

PUMP DISCHARGE PRESSURE:
The total amount of pressure being discharged by a pump. ***NOTE:*** *In mathematical terms, it is the Pump Intake Pressure plus the Net Engine Pressure. (PIP + NEP = PDP)*

RESIDUAL PRESSURE:
That part of the total pressure not used to overcome friction or gravity while forcing water through fire hose, pipe, fittings, and adapters.

STATIC PRESSURE:
Stored or potential energy that is available to force water through pipes and fittings, fire hose, and adapters.

VACUUM:
Any pressure less than atmospheric pressure. ***NOTE:*** *A vacuum is needed to facilitate drafting of water from a static source.*

VELOCITY:
Speed; the rate of motion in a given direction. As defined for this class, it is the speed of water as it leaves the orifice, measured in PSI.

WATER HAMMER:
A force created by the deceleration or acceleration of water. ***NOTE:*** *It generally results from closing a valve or nozzle too quickly.*

1. To find the area of a circle use the following formula:

   $A = \pi r^2$ **or** **$A = \pi d^2 \div 4$**

2. Find the area of a discharge port 2 1/2" in diameter.

$A = \pi r^2$	$A = \pi d^2 \div 4$
$A = (3.14)(1.25)^2$	$A = (3.14)(2.5)^2 \div 4$
$A = 3.14 \times 1.5625$	$A = 3.14 \times 6.25 \div 4$
$A = 4.90625$ SQ. IN.	$A = 19.625 \div 4$
	$A = 4.90625$ SQ. IN.

3. Find the area of a nozzle whose diameter is 1 3/4".

4. Find the water surface area in a 45' diameter storage tank.

5. Find the water surface area in a 10' diameter stock tank.

6. Find the water surface area in a 150' diameter pond.

7. Find the area of a discharge port 5" in diameter.

8. Find the area of a nozzle 2" in diameter.

1. To find the capacity (in gallons) of a cylindrical tank, use the following formula:

SHORT FORMULA (approximate)	**LONG FORMULA** (exact)
	CUBIC FEET (ft^3) = $\pi r^2 L$
GALLONS = $d^2 6L$	
	GALLONS = ft^3 x 7.48

2. Find the capacity of a cylindrical tank that is 10' diameter and 15' long.

$G = d^2 6L$	$ft^3 = \pi r^2 L$
$G = (10)^2(6)(15)$	$ft^3 = (3.14)(5)^2(15)$
G = 100 x 6 x 15	ft^3 = 3.14 x 25 x 15
G = 9000 GALLONS	ft^3 = 1177.5
	G = 1177.5 x 7.48
	G = 8807.7 GALLONS

3. Find the capacity of a cylindrical tank 45' long and 23' in diameter.

4. Find the capacity of a stock water trough that is 12' in diameter and 2' high.

5. Find the capacity of a swimming pool that is 24' in diameter and 4' deep.

6. Find the capacity of a cistern that is 15' in diameter and 12' deep.

1. To calculate water flow in Gallons Per Minute use the following formula:

$GPM = 29.7d^2\sqrt{P}$

P is the discharge or flow pressure

2. Find the GPM flow from a 1" nozzle at 60 PSI.

$GPM = 29.7d^2\sqrt{P}$

$GPM = (29.7)(1)^2\ \sqrt{60}$

GPM = 29.7 X 1 X 7.7460

GPM = 230.0562

3. Find the GPM flow from a 1 5/8" orifice at 55 PSI.

NOTE: To find the decimal equivalent of 5/8, divide 8 into 5 (5 ÷ 8 = .625)

$GPM = 29.7d^2\sqrt{P}$

$GPM = (29.7)(1.625)^2\ \sqrt{55}$

GPM = 29.7 X 2.640625 X 7.4161984

GPM = 581.62592

4. Find the GPM flow from a 2" master stream tip operating at 95 PSI.

5. Find the GPM flow from a 1 7/8" tip at 75 PSI

6. Find the GPM discharge from a 2 1/2" port at 50 PSI.

7. Find the GPM discharge from a 5" steamer port at 22 PSI.

1. To calculate friction loss use the following formula:

$$FL = CQ^2L$$

FL is friction loss
C is Friction Loss Coefficient
Q is GPM flow divided by 100
L is Hose Length divided by 100

FRICTION LOSS COEFFICIENTS - SINGLE LINE	
Hose Diameter (in inches)	**Coefficient (C)**
3/4” Booster	1100.00
1” Booster	150.00
1 1/2”	24.00
1 3/4”	15.50
2 1/2”	2.00
3”	0.80
3 1/2”	0.34
4”	0.20
4 1/2”	0.10
5”	0.08
6”	0.05

FRICTION LOSS COEFFICIENTS - SIAMESED LINES OF EQUAL LENGTH	
Hose Diameter (in inches)	**Coefficient (C)**
Two 2 1/2”	0.50
Three 2 1/2”	0.22
One 3” & one 2 1/2”	0.30
Two 3”	0.20
Two 2 1/2” & One 3”	0.16
Two 3” & One 2 1/2”	0.12

2. Find the friction loss in 100' of 2 1/2" hose flowing 500 GPM.

   a. C = Friction Loss Coefficient for 2 1/2" hose

      C = 2

   b. Q = GPM ÷ 100

      Q = 500 ÷ 100

      Q = 5

c. L = Hose Length ÷ 100

L = 100 ÷ 100

L = 1

d. $FL = CQ^2L$

$FL = (2)(5)^2(1)$

FL = 2 x 25 x 1

FL = 50 x 1

FL = 50 PSI

3. Find friction loss in 500' of 2 1/2" hose flowing 300 GPM.

a. C = Friction Loss Coefficient for 2 1/2" hose

C = 2

b. Q = GPM ÷ 100

Q = 300 ÷ 100

Q = 3

c. L = Hose Length ÷ 100

L = 500 ÷ 100

L = 5

d. $FL = CQ^2L$

$FL = (2)(3)^2(5)$

FL = 2 x 9 x 5

FL = 18 x 5

FL = 90 PSI

4. Find friction loss in 100' of 1 3/4" hose flowing 200 GPM.

   a. C = Friction Loss Coefficient for 1 3/4" hose

      C = 15.5

   b. Q = GPM ÷ 100

      Q = 200 ÷ 100

      Q = 2

   c. L = Hose Length ÷ 100

      L = 100 ÷ 100

      L = 1

   d. $FL = CQ^2L$

      $FL = (15.5)(2)^2(1)$

      FL = 15.5 x 4 x 1

      FL = 62 x 1

      FL = 62 PSI

5. Find friction loss in 500' of 3" hose flowing 500 GPM.

   a. C = Friction Loss Coefficient for 3" hose

      C = .8

   b. Q = GPM ÷ 100

      Q = 500 ÷ 100

      Q = 5

   c. L = Hose Length ÷ 100

      L = 500 ÷ 100

      L = 5

d. $FL = CQ^2L$

$FL = (.8)(5)^2(5)$

$FL = .8 \times 25 \times 5$

$FL = 20 \times 5$

$FL = 100$ PSI

6. Find friction loss in 150' of 1 1/2" hose flowing 60 GPM.

a. C = Friction Loss Coefficient for 1 1/2" hose

$C = 24$

b. Q = GPM ÷ 100

$Q = 60 \div 100$

$Q = .6$

c. L = Hose Length ÷ 100

$L = 150 \div 100$

$L = 1.5$

d. $FL = CQ^2L$

$FL = (24)(.6)^2(1.5)$

$FL = 24 \times .36 \times 1.5$

$FL = 8.64 \times 1.5$

$FL = 12.96$ PSI

7. Find friction loss in 500' of double 3" lines flowing 1000 GPM.

a. C = Friction Loss Coefficient for double 3" lines

$C = .2$

b. Q = GPM ÷ 100

$Q = 1000 \div 100$

$Q = 10$

c. $L = \text{Hose Length} \div 100$

$L = 500 \div 100$

$L = 5$

d. $FL = CQ^2L$

$FL = (.2)(10)^2(5)$

$FL = .2 \times 100 \times 5$

$FL = 20 \times 5$

$FL = 100$ PSI

8. Find the friction loss in 1000' of 5" hose flowing 1000 GPM.

9. Find the friction loss in 150' of 1 1/2" hose flowing 125 GPM.

10. Find the friction loss in 750' of one 3" hose and one 2 1/2" line flowing 750 GPM.

11. Find the friction loss in 200' of 3/4" booster hose flowing 20 GPM.

12. Find the friction loss in 1200' of one 3" and one 2 1/2" line flowing 1000 GPM.

13. Find the friction loss in 700' of one 3" and one 2 1/2" flowing 1000 GPM.

14. Find the friction loss in 1000' of two 3" and one 2 1/2" flowing 1200 GPM.

1. The formula for finding required Pump Discharge Pressure (PDP) is:

PDP = NP + FL

NP stands for nozzle pressure
FL stands for friction loss

NOTE

FOG NOZZLES ARE DESIGNED TO OPERATE AND DELIVER RATED GALLONAGES AT 100 PSI. ALWAYS USE 100 PSI NOZZLE PRESSURE TO CALCULATE PUMP DISCHARGE PRESSURE WHEN UTILIZING FOG NOZZLES.

2. Find the pump discharge pressure required for supplying 200' of 2 1/2" hose equipped with a 200 GPM fog nozzle operating at 100 PSI nozzle pressure.

   a. C = Friction Loss Coefficient for 2 1/2" hose

      C = 2

   b. Q = GPM ÷ 100

      Q = 200 ÷ 100

      Q = 2

   c. L = Hose Length ÷ 100

      L = 200 ÷ 100

      L = 2

   d. $FL = CQ^2L$

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

      FL = 2 x 4 x 2

      FL = 8 x 2

      FL = 16 PSI

   e. PDP = NP + FL

      PDP = 100 + 16

      PDP = 116 PSI

3. Find the pump discharge pressure required for supplying 200' of 1 3/4" equipped with 200 GPM automatic fog nozzle.

   a. C = Friction Loss Coefficient for 1 3/4" hose

      C = 15.5

   b. Q = GPM ÷ 100

      Q = 200 ÷ 100

      Q = 2

   c. L = Hose Length ÷ 100

      L = 200 ÷ 100

      L = 2

   d. $FL = CQ^2L$

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

      FL = 15.5 x 4 x 2

      FL = 62 x 2

      FL = 124 PSI

   e. PDP = NP + FL

      PDP = 100 + 124

      PDP = 224 PSI

4. Find the pump discharge pressure required for supplying 200' of 2 1/2" hose equipped with a 350 GPM fog nozzle operating at 100 PSI nozzle pressure.

5. Find the pump discharge pressure required for supplying 200' of 1 3/4" hose equipped with 350 GPM automatic fog nozzle.

Fireground activities often prohibit the use of formulas because of existing conditions and the lack of time, so rules of thumb can be used when it is necessary to calculate quickly. There are several rules of thumb used for quick calculations, and the most common are presented here. The order by which these rules are presented in no way signifies their value or importance. Their adaptation must be made locally and to the best advantage of all concerned.

Some fire departments use 3" hose with 2 1/2" couplings to supply master streams. Three inch hose is especially beneficial when supplying ladder pipes because of the reduction of friction loss. The friction loss per 100' of 3" hose with 2 1/2" couplings may be determined by the formula **$FL = Q^2$**, when the flow is less than 500 GPM. The symbol Q must be stated in the number of hundreds of gallons per minute, or gpm divided by 100. This method and formula is not as accurate as using the conversion factor from the table, but it is more rapid and sufficiently accurate for fireground operations. For practical purposes, 3" hose with either 3" or 2 1/2" couplings can be treated identically.

Using the condensed Q formula:

1. What is the friction loss per 100' of 3" flowing 200 GPM?

$Q = GPM \div 100$	$FL = Q^2$
$Q = 200 \div 100$	$FL = (2)^2$
$Q = 2$	$FL = 2 \times 2$
	$FL = 4$ PSI

2. What is the friction loss per 100' of 3" hose flowing 500 GPM?

3. What is the pump discharge pressure required to supply a 500 GPM master stream with a 600' lay of 3" hose?

Fire stream calculations on the fireground require methods that are easily understood and applicable to mnemonic use. The following method of using one's hand and fingers applies only to 2 1/2" hose for flows from 100 - 500 GPM.

Starting with the thumb of the left hand, each finger is numbered at the tip in terms of hundreds of gallons per minute. Returning to the thumb, and again moving from left to right, the base of each finger is given a successive even number, beginning with two. The friction loss for 100' of 2 1/2" hose at a desired flow is determined by selecting the finger to which the desired flow has been assigned, and multiplying the number at the tip of the finger by the number at the base of the finger. The friction loss for a flow of 500 GPM can be found by

using the numbers assigned to the little finger, or (5)(10) = 50 PSI friction loss per 100' of 2 1/2" hose. The friction loss for a flow of 200 gpm is found using the numbers assigned to the index finger, or (2)(4) = 8 PSI friction loss per 100' of 2 1/2" hose.

Since nozzle capacities vary in GPM, the nearest half-hundred can be used with slight variations. The numbers 1.5, 2.5, 3.5 and 4.5 can be used for flows of 150, 250, 350 and 450 GPM, respectively. These half-hundred figures can be assigned to the spaces between the fingers. Then by using the odd numbers 3, 5, 7, and 9 to couple with the half-hundred fingers, sufficiently accurate results can be obtained for the friction loss per 100' of 2 1/2" hose.

The counting finger method can also be used for 3" hose by numbering the base of the fingers with 1, 2, 3, 4 and 5. Flows through 3" hose must be rounded to the nearest hundred.

Using the finger counting method:

1. Find the friction loss per 100' of 2 1/2" hose flowing 300 GPM.

2. Find the friction loss per 100' of 2 1/2" hose flowing 500 GPM.

3. Find the friction loss per 100' of 2 1/2" hose flowing 150 GPM.

4. Find the friction loss per 100' of 3" hose flowing 400 GPM.

5. Find the friction loss per 100' of 3" hose flowing 200 GPM.

6. Find the total friction loss in a 500' line of 2 1/2" hose flowing 400 GPM.

7. Find the total friction loss in a 600' line of 3" hose flowing 300 GPM.

8. Find the total friction loss in a 400' line of 2 1/2" hose flowing 450 GPM.

9. Determine the required pump discharge pressure to supply a 500 GPM master fog stream through a 3" line 400' in length.

10 Determine the required pump discharge pressure to supply a 250 GPM fog nozzle through 300' of 2 1/2" hose.