

1 INLET

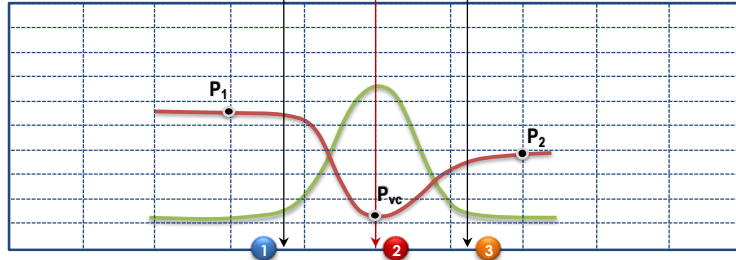
2 VENA CONTRACTA

3 OUTLET

INLET

OUTLET

— VELOCITY
— PRESSURE



H₁ : 22 ft



FLOW →

200 gpm

60 °F

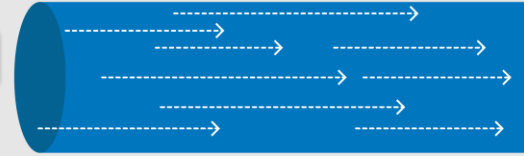
BALL VALVE
2 3/8 φ seat



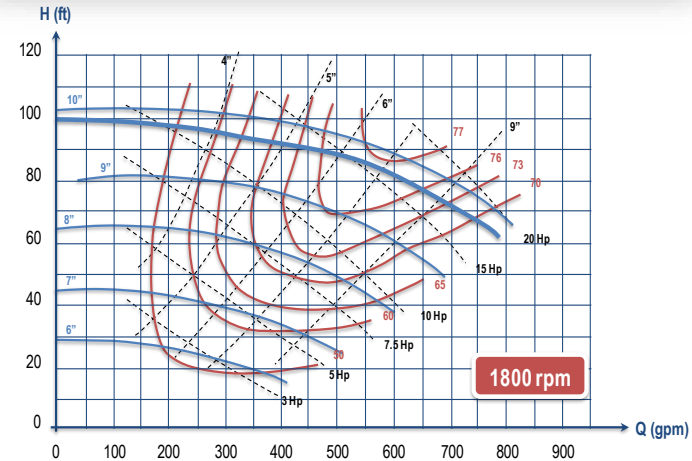
P₂ : ATM

→ FLOW

LAMINAR
FLOW



TURBULENT
FLOW



CONCRETE EXAMPLE # 1

NATURE OF FLOW IN PIPE

DETERMINING REYNOLDS NUMBER
AND FRICTION FACTOR FOR A STEEL PIPE

- ▶ Water at 80°F is flowing through 70 feet of 2" standard steel pipe schedule 40 at a rate of 50 gpm

Let's find the Reynolds number (Re) and the friction factor (f)

$$Re = \frac{Dv\rho}{\mu}$$

D : Pipe internal diameter (ft)

v : Mean velocity of flow (ft/s)

ρ : Weight density of fluid (lb/ft³)

μ : Absolute viscosity (lb/ft.s)

- Water at 80°F is flowing through 70 feet of 2" standard steel pipe schedule 40 at a rate of 50 gpm

Let's find the Reynolds number (Re) and the friction factor (f)

Weight density of water at 80°F (ρ) : 62.212 lb/ft³

Dynamic viscosity of water at 80°F (μ) : 0.85 cP

Pipe internal diameter (d) :

Rate of flow (Q) : 50 gpm

Reynolds number (Re) : 89691

Friction factor (f) : ~0.022

$$Re = 50.66 \frac{Q\rho}{d\mu}$$

D : Pipe internal diameter (ft)

Q : Rate of flow (gpm)

ρ : Weight density of fluid (lb/ft³)

μ : Absolute viscosity (lb/ft.s)

TURBULENT

Re > 4000

CONCRETE EXAMPLE # 2

VALVE RESISTANCE

Y-PATTERN GLOBE VALVES :
DETERMINING L , L/D AND C_v

- ▶ A 6" class schedule 40, 125 iron Y-pattern globe valve has a flow coefficient C_v of 600

Let's find the resistance coefficient (K), the equivalent lengths (L/D) and L for flow in zone of complete turbulence

Pipe internal diameter (d) : 6.065 in

Pipe internal diameter (D) : 0.5054 ft

$$K = 890.3 \frac{d^2}{C_v^2}$$

Resistance coefficient (K) : 3.35

Friction factor (f) :

$$K = f \frac{L}{D}$$

- ▶ A 6" class schedule 40, 125 iron Y-pattern globe valve has a flow coefficient C_v of 600

Let's find the resistance coefficient (K), the equivalent lengths (L/D) and L for flow in zone of complete turbulence

Pipe internal diameter (d) : 6.065 in

Pipe internal diameter (D) : 0.5054 ft

$$K = 890.3 \frac{d^2}{C_v^2}$$

Resistance coefficient (K) : 3.35

Friction factor (f) : ~0.015 *(from chart)*

$$K = f \frac{L}{D}$$

L/D : 223

Pipe length (L) : 113 ft

CONCRETE EXAMPLE # 3

VALVE RESISTANCE

CONVENTIONAL GLOBE VALVES :
DETERMINING L , L/D AND C_v

- ▶ A 4" class 600 schedule 80 steel conventional angle valve with full area seat

Let's find the resistance coefficient (K), the flow coefficient (C_v), the equivalent lengths (L/D) and L for flow in zone of complete turbulence

Pipe internal diameter (d) : 3.826 in

Pipe internal diameter (D) : 0.319 ft

$$K = 890.3 \frac{d^2}{C_v^2}$$

Resistance coefficient (K) : 2.4

Friction factor (f) : 0.016

Flow coefficient (C_v) : 282

L/D : 150

Pipe length (L) : 47.8 ft

$$K = f \frac{L}{D}$$

CONCRETE EXAMPLE # 4

VALVE RESISTANCE

GATE VALVES :
DETERMINING K, L/D AND L

- ▶ A 6x4" class 600 schedule 80 steel gate valve with inlet and outlet ports conically tapered from back of body rings to valve ends. The angle $\theta \sim 13^\circ$

Let's find the resistance coefficient (K), the equivalent lengths (L/D) and L for flow in zone of complete turbulence

Pipe internal diameter (d_1) : 4 in

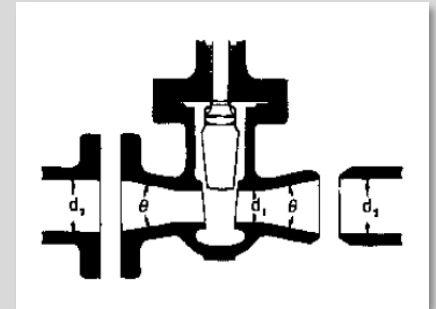
Pipe internal diameter (d_2) : 5.761 in

Resistance coefficient (K) : 1.06

Friction factor (f) : ~0.015

L/D : 70.7

Pipe length (L) : 34 ft



$$K = f \frac{L}{D}$$

CONCRETE EXAMPLE # 5

SIZING LIFT CHECK VALVES

- ▶ A globe type lift check valve is required in a 3" schedule 40 horizontal pipe carrying 70°F water at the rate of 80 gpm

Let's find the proper size for this check valve and the corresponding pressure drop

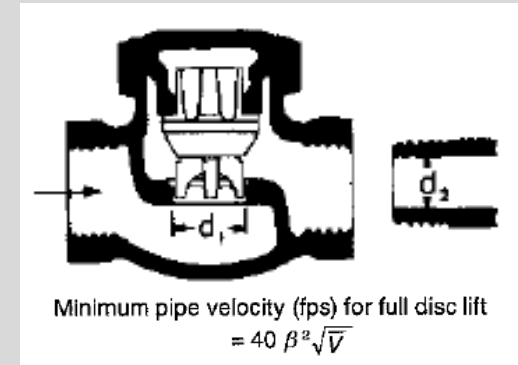
Valve internal diameter (d_1) : 3.068 in

Pipe internal diameter (d_2) : 3.068 in

Water weight density at 70°F (ρ) : 62.298 lb/ft³

Water specific volume at 70°F ($\bar{V}$) : 0.01605 ft³/lb

Minimum velocity ($v_{\min}$) = $40 \times (3.068/3.068)^2 \times (0.01605)^{0.5}$



- ▶ A globe type lift check valve is required in a 3" schedule 40 horizontal pipe carrying 70°F water at the rate of 80 gpm

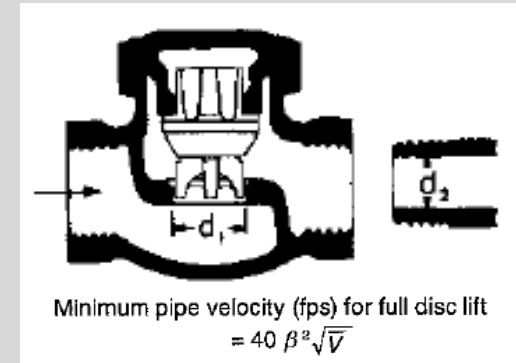
Let's find the proper size for this check valve and the corresponding pressure drop

Valve internal diameter (d_1) : 3.068 in

Pipe internal diameter (d_2) : 3.068 in

Water weight density at 70°F (ρ) : 62.298 lb/ft³

Water specific volume at 70°F ($\bar{V}$) : 0.01605 ft³/lb



Minimum velocity ($v_{\min}$) = 5.1 ft/s

Actual velocity ($v_{3''}$) :

3" valve too large

- ▶ A globe type lift check valve is required in a 3" schedule 40 horizontal pipe carrying 70°F water at the rate of 80 gpm

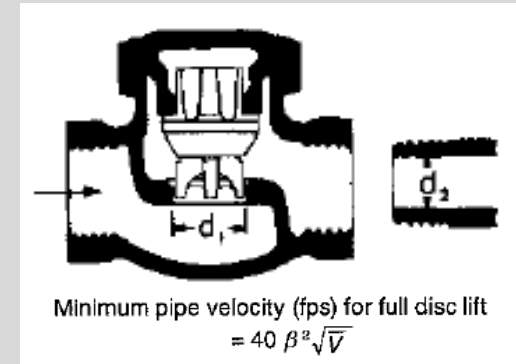
Let's find the proper size for this check valve and the corresponding pressure drop

Valve internal diameter (d_1) : ~~3.068 in~~

Pipe internal diameter (d_2) : 3.068 in

Water weight density at 70°F (ρ) : 62.298 lb/ft³

Water specific volume at 70°F ($\bar{V}$) : 0.01605 ft³/lb



Minimum velocity ($v_{\min}$) = 5.1 ft/s

Actual velocity ($v_{3''}$) : 3.47 ft/s

3" valve too large

Actual velocity ($v_{2\frac{1}{2}''}$) :

2 1/2" valve OK

- ▶ A globe type lift check valve is required in a 3" schedule 40 horizontal pipe carrying 70°F water at the rate of 80 gpm

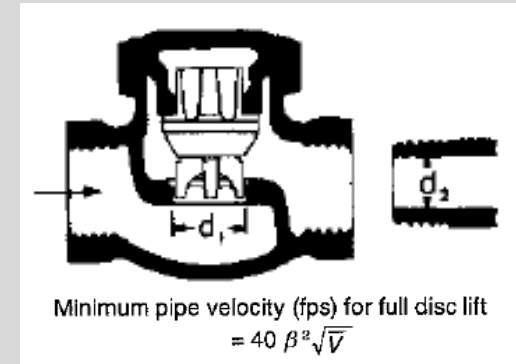
Let's find the proper size for this check valve and the corresponding pressure drop

Valve internal diameter (d_1) : ~~3.068 in~~ 2.469 in (2 ½" Schedule 40)

Pipe internal diameter (d_2) : 3.068 in

Water weight density at 70°F (ρ) : 62.298 lb/ft³

Water specific volume at 70°F ($\bar{V}$) : 0.01605 ft³/lb



Minimum velocity ($v_{\min}$) = 5.1 ft/s

Actual velocity ($v_{2 \frac{1}{2}''}$) : 5.36 ft/s

2 ½" valve OK

Resistance coefficient (K) : 26.2

- ▶ A globe type lift check valve is required in a 3" schedule 40 horizontal pipe carrying 70°F water at the rate of 80 gpm

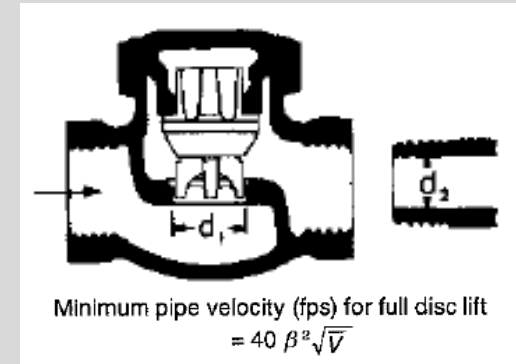
Let's find the proper size for this check valve and the corresponding pressure drop

Valve internal diameter (d_1) : ~~3.068 in~~ 2.469 in (2 ½" Schedule 40)

Pipe internal diameter (d_2) : 3.068 in

Water weight density at 70°F (ρ) : 62.298 lb/ft³

Water specific volume at 70°F ($\bar{V}$) : 0.01605 ft³/lb



Minimum velocity ($v_{\min}$) = 5.1 ft/s

Actual velocity ($v_{2 \frac{1}{2}''}$) : 5.36 ft/s

2 ½" valve OK

Resistance coefficient (K) : 26.2

Pressure drop (ΔP) : 2.1 psi

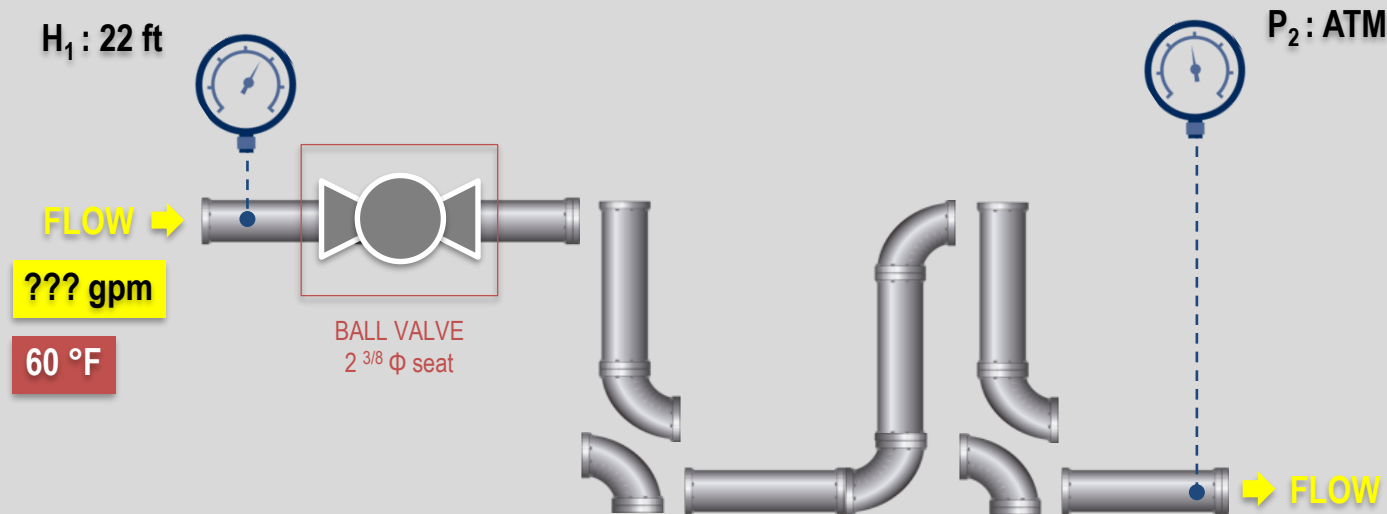
CONCRETE EXAMPLE # 6

BALL VALVE

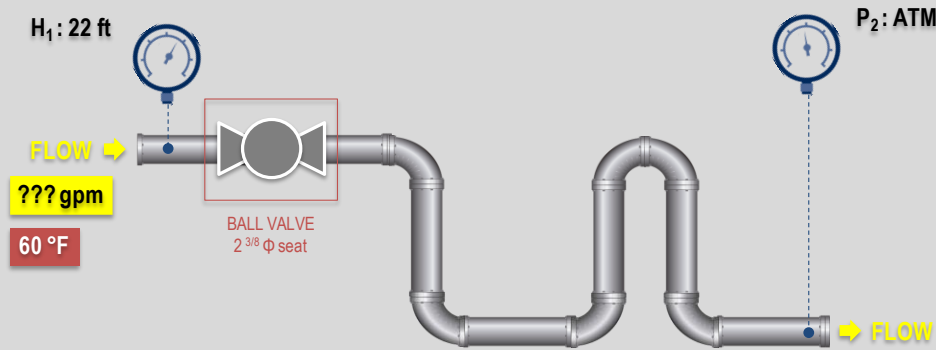
FLUID VELOCITY AND RATE OF DISCHARGE

- Water at 60°F discharges from a tank with a 22 ft head to atmospheric through :
- 200 ft, 3" schedule 40 pipe
 - 6 x 3" standard 90° threaded elbows
 - 1 x 3" flanged ball valve having a 2 ½" diameter seat, 25° conical inlet and 25° conical outlet

Let's find the velocity of flow in the pipe and rate of discharge in gpm



CONCRETE EXAMPLE #6



- 200 ft, 3" schedule 40 pipe
- 6 x 3" standard 90° threaded elbows
- 1 x 3" flanged ball valve having a 2 1/2" diameter seat
25° conical inlet and 25° conical outlet

Valve internal diameter (d_1) : 2.375 in

Pipe internal diameter (d_2) : 3.068 in

Water weight density at 60°F (ρ) : 62.298 lb/ft³

Water dynamic viscosity at 60°F (μ) : 1.1 cP

Valve angle (θ) : 25°

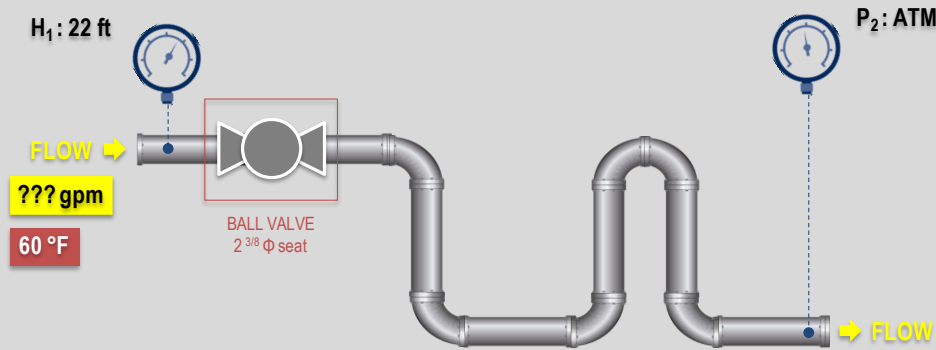
Average head (h_L) : 22 ft

h_L : Loss of static pressure head due to fluid flow (ft)

K : Resistance coefficient (unitless)

v : Mean velocity of flow (ft/s)

g : Gravitational acceleration = 32.174 ft/s²



- 200 ft, 3" schedule 40 pipe
- 6 x 3" standard 90° threaded elbows
- 1 x 3" flanged ball valve having a $2 \frac{1}{2}$ diameter seat 25° conical inlet and 25° conical outlet

$$K = f \frac{L}{D}$$

Valve internal diameter (d_1) : 2.375 in

Pipe internal diameter (d_2) : 3.068 in

Water weight density at 60°F (ρ) : 62.298 lb/ft³

Water dynamic viscosity at 60°F (μ) : 1.1 cP

Valve angle (θ) : 25°

Average head (h_L) : 22 ft

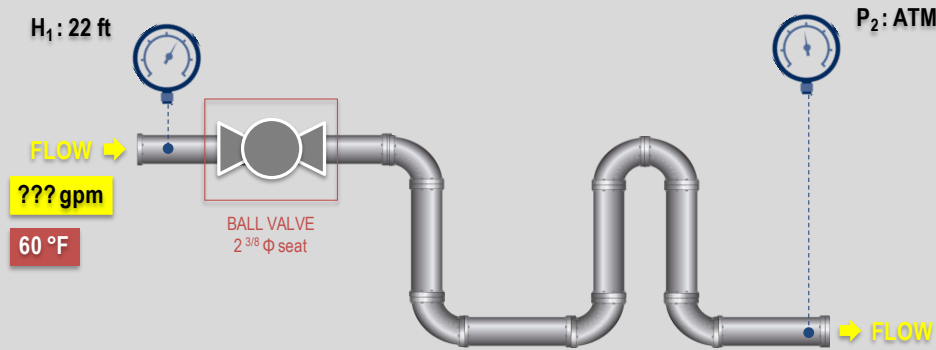
Valve resistance coefficient (K_1) : 0.6

Elbows resistance coefficient (K_2) : 3.24

Pipe resistance coefficient (K_3) : 14

Entrance resistance coefficient (K_4) : 0.5

Exit resistance coefficient (K_5) : 1



- 200 ft, 3" schedule 40 pipe
- 6 x 3" standard 90° threaded elbows
- 1 x 3" flanged ball valve having a 2 1/2" diameter seat 25° conical inlet and 25° conical outlet

Valve internal diameter (d_1) : 2.375 in

Pipe internal diameter (d_2) : 3.068 in

Water weight density at 60°F (ρ) : 62.298 lb/ft³

Water dynamic viscosity at 60°F (μ) : 1.1 cP

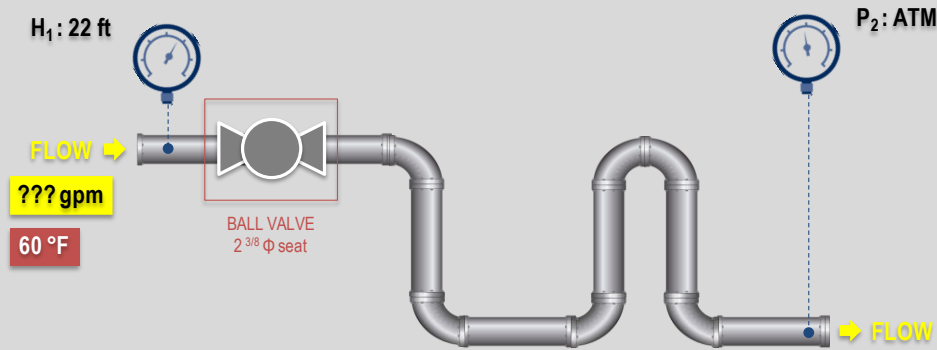
Valve angle (θ) : 25°

Average head (h_L) : 22 ft

System resistance coefficient (K_T) : 19.34

SUM OF :

- Valve resistance coefficient (K_1) : 0.6
- Elbows resistance coefficient (K_2) : 3.24
- Pipe resistance coefficient (K_3) : 14
- Entrance resistance coefficient (K_4) : 0.5
- Exit resistance coefficient (K_5) : 1



- 200 ft, 3" schedule 40 pipe
- 6 x 3" standard 90° threaded elbows
- 1 x 3" flanged ball valve having a 2 1/2" diameter seat 25° conical inlet and 25° conical outlet

$$h_L = K \frac{v^2}{2g}$$

Valve internal diameter (d_1) : 2.375 in

Pipe internal diameter (d_2) : 3.068 in

Water weight density at 60°F (ρ) : 62.298 lb/ft³

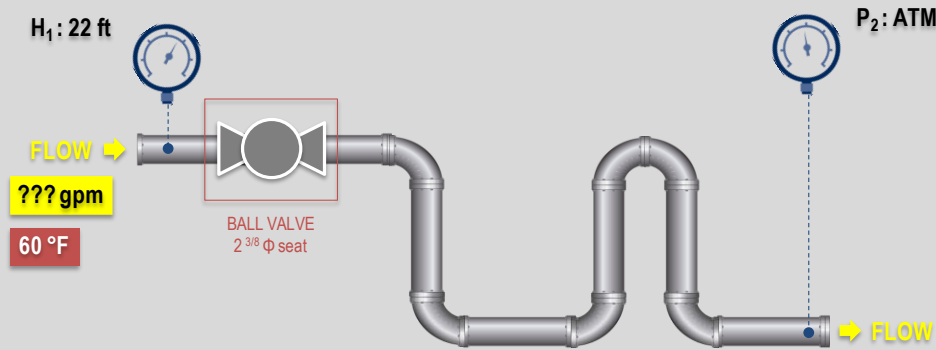
Water dynamic viscosity at 60°F (μ) : 1.1 cP

Valve angle (θ) : 25°

Average head (h_L) : 22 ft

System resistance coefficient (K_T) : 19.34

Velocity of flow (v) :



- 200 ft, 3" schedule 40 pipe
- 6 x 3" standard 90° threaded elbows
- 1 x 3" flanged ball valve having a 2 1/2 diameter seat 25° conical inlet and 25° conical outlet

$$v = \sqrt{\frac{2gh_L}{K}}$$

Valve internal diameter (d_1) : 2.375 in

Pipe internal diameter (d_2) : 3.068 in

Water weight density at 60°F (ρ) : 62.298 lb/ft³

Water dynamic viscosity at 60°F (μ) : 1.1 cP

Valve angle (θ) : 25°

Average head (h_L) : 22 ft

System resistance coefficient (K_T) : 19.34

Velocity of flow (v) : 8.55 ft/s

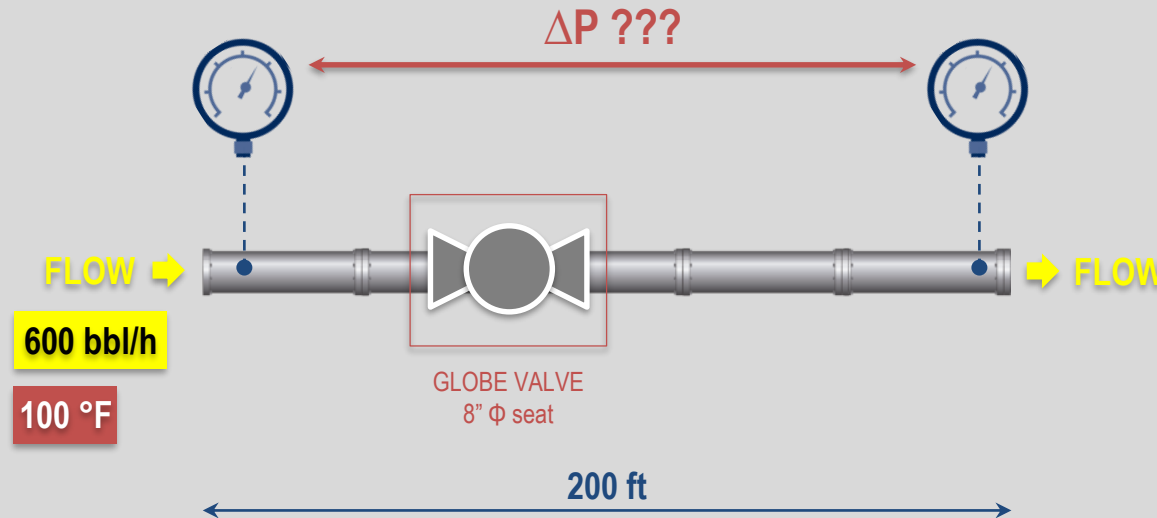
Rate of flow (Q) : 197 gpm

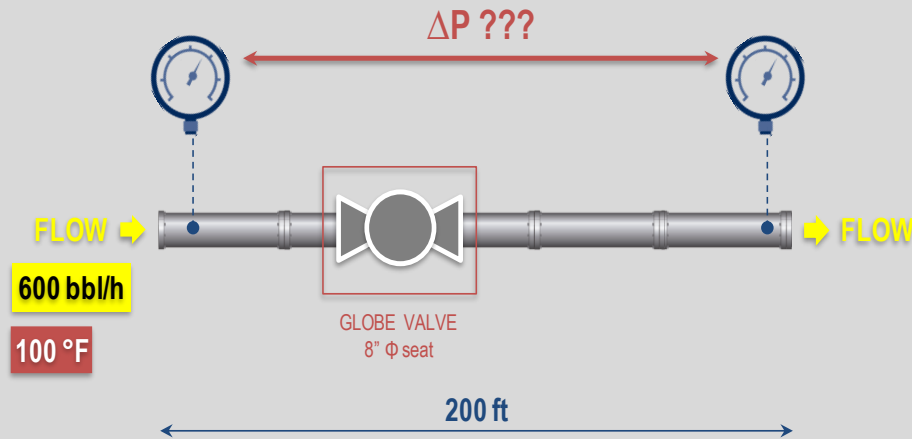
CONCRETE EXAMPLE # 7

**LAMINAR FLOW IN VALVES
FITTINGS AND PIPE (1/2)**

- ▶ S.A.E 30 oil at 100°F is flowing at a rate of 600 bbl/h through 200 ft of 8" schedule 40 pipe, in which an 8" conventional globe valve with full area seat is installed

Let's find the pressure drop due to flow through the pipe and valve





- 200 ft, 8" schedule 40 pipe
- 8" globe valve

$$\rho_{oil}^{100^{\circ}F} = \rho_{water}^{60^{\circ}F} \times S_{oil}^{100^{\circ}F}$$

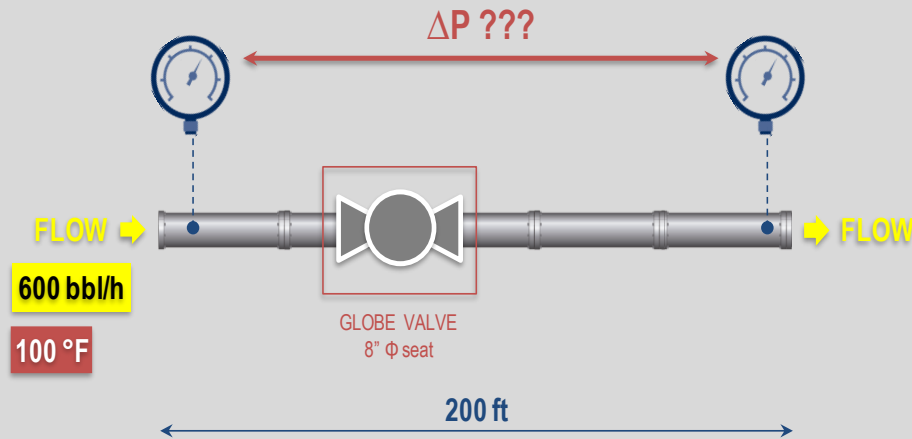
Valve internal diameter (d_1) : 2.375 in

Pipe internal diameter (d_2) : 7.981 in

Oil dynamic viscosity at 100°F (μ_{oil}) :

Oil specific gravity at 100°F ($sp.gr_{oil}$) :

Oil weight density at 100°F (ρ_{oil}) :



- 200 ft, 8" schedule 40 pipe
- 8" globe valve

$$\rho_{oil}^{100^{\circ}F} = 62.364 \frac{\text{lb}}{\text{ft}^3} \times 0.87$$

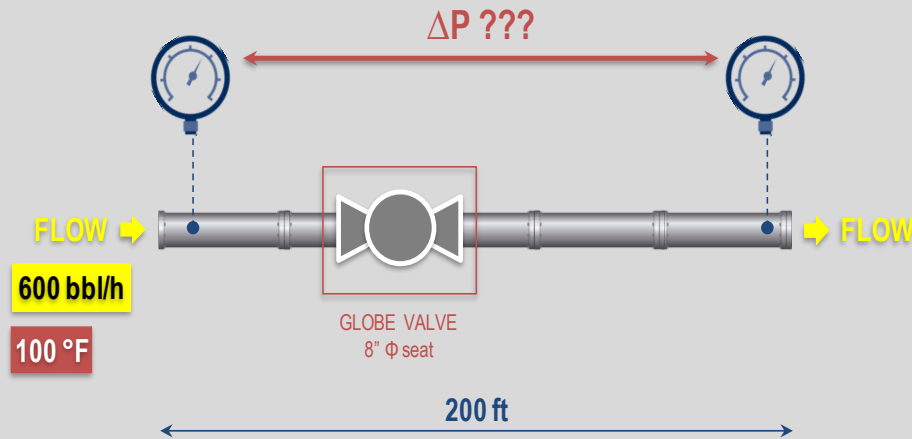
Valve internal diameter (d_1) : 2.375 in

Pipe internal diameter (d_2) : 7.981 in

Oil dynamic viscosity at 100°F (μ_{oil}) : 130 cP

Oil specific gravity at 100°F (sp.gr_{oil}) : 0.87

Oil weight density at 100°F (ρ_{oil}) :



- 200 ft, 8" schedule 40 pipe
- 8" globe valve

$$\rho_{oil}^{100^{\circ}F} = 54.26 \frac{\text{lb}}{\text{ft}^3}$$

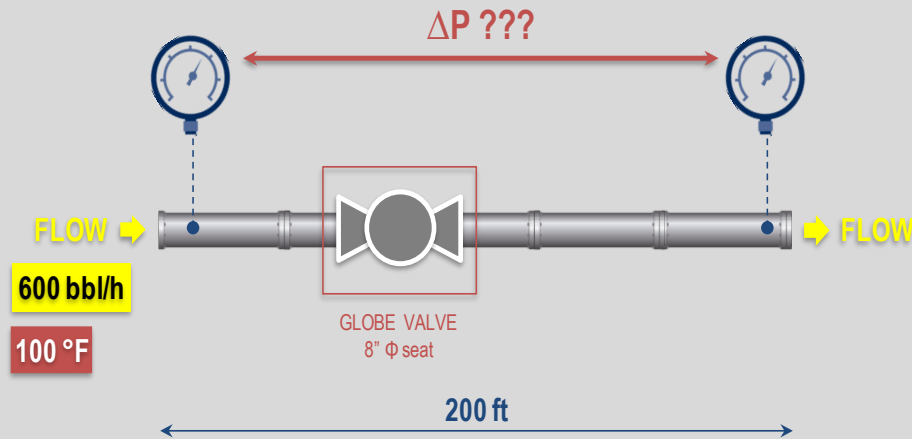
Valve internal diameter (d_1) : 2.375 in

Pipe internal diameter (d_2) : 7.981 in

Oil dynamic viscosity at 100°F (μ_{oil}) : 130 cP

Oil specific gravity at 100°F (sp.gr_{oil}) : 0.87

Oil weight density at 100°F (ρ_{oil}) :



- 200 ft, 8" schedule 40 pipe
- 8" globe valve

$$f = \frac{64}{Re} = \frac{64\mu}{124dvp}$$

Valve internal diameter (d_1) : 2.375 in

Pipe internal diameter (d_2) : 7.981 in

Oil dynamic viscosity at 100°F (μ_{oil}) : 130 cP

Oil specific gravity at 100°F ($sp.gr_{oil}$) : 0.87

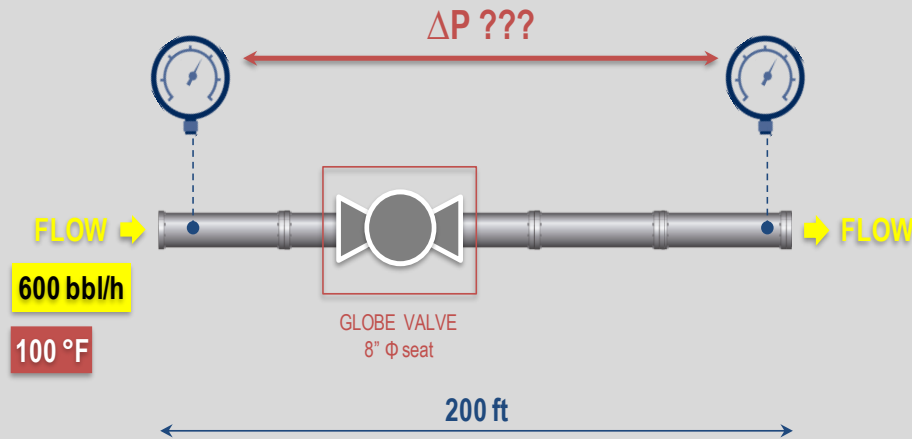
Oil weight density at 100°F (ρ_{oil}) : 54.26 lb/ft³

Rate of flow : 600 bbl/h = 420 gpm

Reynolds number (Re) :

Pipe friction factor (f) : 0.058

Pipe resistance coefficient (K_1) :



- 200 ft, 8" schedule 40 pipe
- 8" globe valve

$$K = f \frac{L}{D}$$

Nature of flow in pipe :

LAMINAR FLOW

Reynolds number (Re) : 1112

Pipe friction factor (f) : 0.058

Pipe resistance coefficient (K₁) :

Valve internal diameter (d₁) : 2.375 in

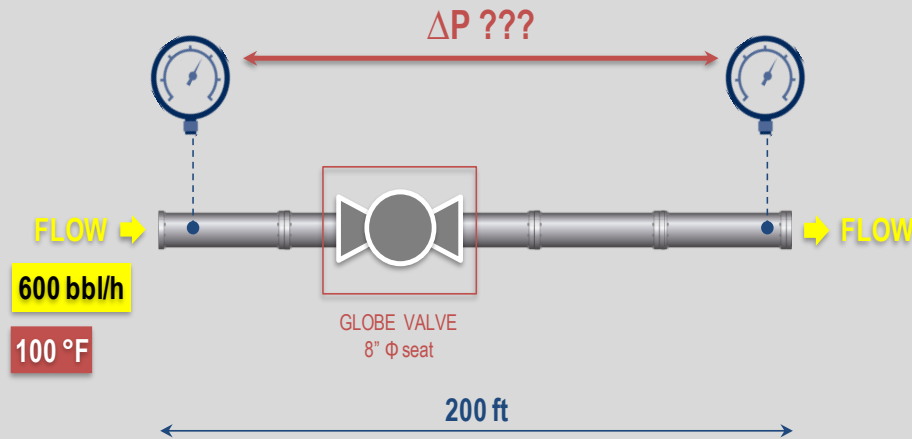
Pipe internal diameter (d₂) : 7.981 in

Oil dynamic viscosity at 100°F (μ_{oil}) : 130 cP

Oil specific gravity at 100°F (sp.gr_{oil}) : 0.87

Oil weight density at 100°F (ρ_{oil}) : 54.26 lb/ft³

Rate of flow : 600 bbl/h = 420 gpm



- 200 ft, 8" schedule 40 pipe
- 8" globe valve

$$K = f \frac{L}{D}$$

Nature of flow in pipe :

LAMINAR FLOW

Reynolds number (Re) : 1112

Pipe friction factor (f) : 0.058

Pipe resistance coefficient (K_1) :

Valve resistance coefficient (K_2) :

System resistance coefficient (K_T) : $K_1 + K_2$

Valve internal diameter (d_1) : 2.375 in

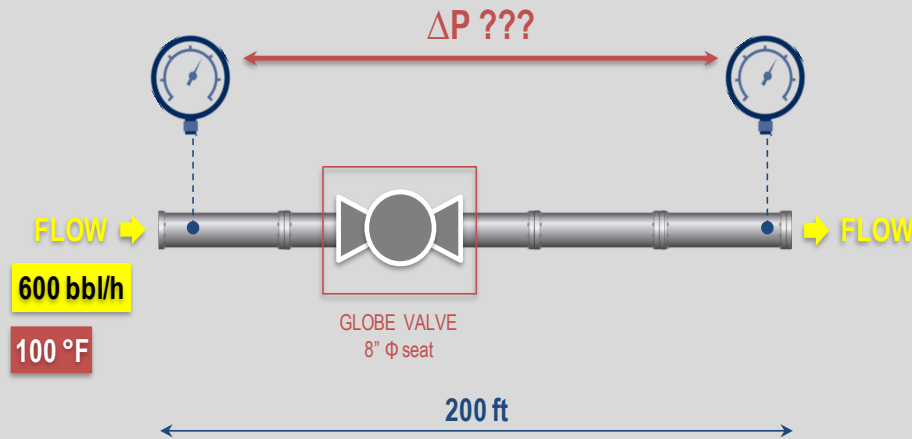
Pipe internal diameter (d_2) : 7.981 in

Oil dynamic viscosity at 100°F (μ_{oil}) : 130 cP

Oil specific gravity at 100°F (sp.gr_{oil}) : 0.87

Oil weight density at 100°F (ρ_{oil}) : 54.26 lb/ft³

Rate of flow : 600 bbl/h = 420 gpm



- 200 ft, 8" schedule 40 pipe
- 8" globe valve

$$K = f \frac{L}{D}$$

Nature of flow in pipe :

LAMINAR FLOW

Reynolds number (Re) : 1112

Pipe friction factor (f) : 0.058

Pipe resistance coefficient (K_1) : 17.44

Valve resistance coefficient (K_2) : 4.76

System resistance coefficient (K_T) :

Valve internal diameter (d_1) : 2.375 in

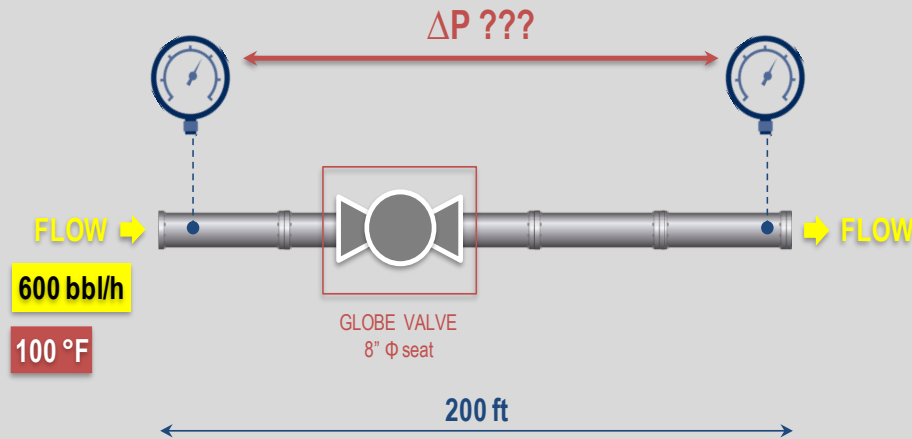
Pipe internal diameter (d_2) : 7.981 in

Oil dynamic viscosity at 100°F (μ_{oil}) : 130 cP

Oil specific gravity at 100°F (sp.gr_{oil}) : 0.87

Oil weight density at 100°F (ρ_{oil}) : 54.26 lb/ft³

Rate of flow : 600 bbl/h = 420 gpm



- 200 ft, 8" schedule 40 pipe
- 8" globe valve

Valve internal diameter (d_1) : 2.375 in

Pipe internal diameter (d_2) : 7.981 in

Oil dynamic viscosity at 100°F (μ_{oil}) : 130 cP

Oil specific gravity at 100°F ($sp.gr_{oil}$) : 0.87

Oil weight density at 100°F (ρ_{oil}) : 54.26 lb/ft³

Rate of flow : 600 bbl/h = 420 gpm

Reynolds number (Re) : 1112

Nature of flow in pipe :

LAMINAR FLOW

Pipe friction factor (f) : 0.058

System resistance coefficient (K_T) : 22.2

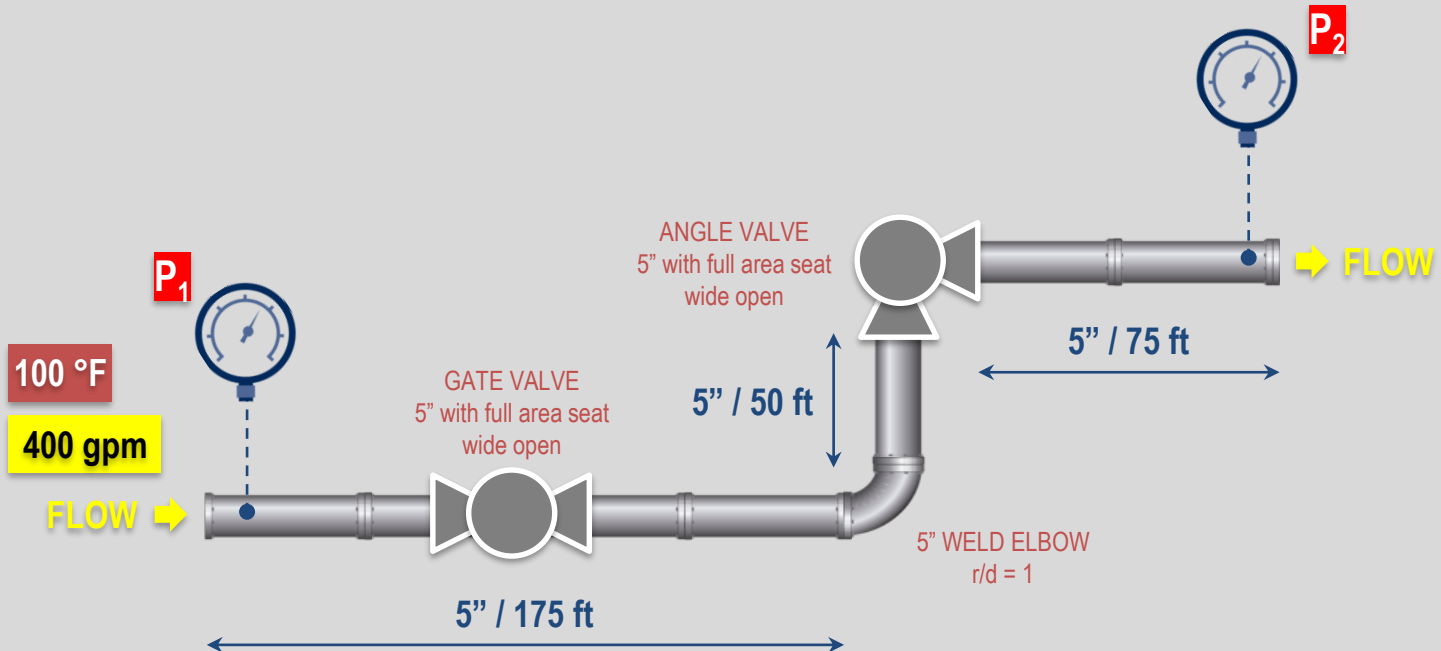
Pressure drop (ΔP) :

CONCRETE EXAMPLE # 8

**LAMINAR FLOW IN VALVES
FITTINGS AND PIPE (2/2)**

- ▶ S.A.E 30 oil at 100°F is flowing at a rate of 400 gpm through 5" schedule 40 pipe as depicted in the following figure

Let's find the pressure difference between gauges P_1 and P_2



Pipe internal diameter (d_2) : 5.047 in

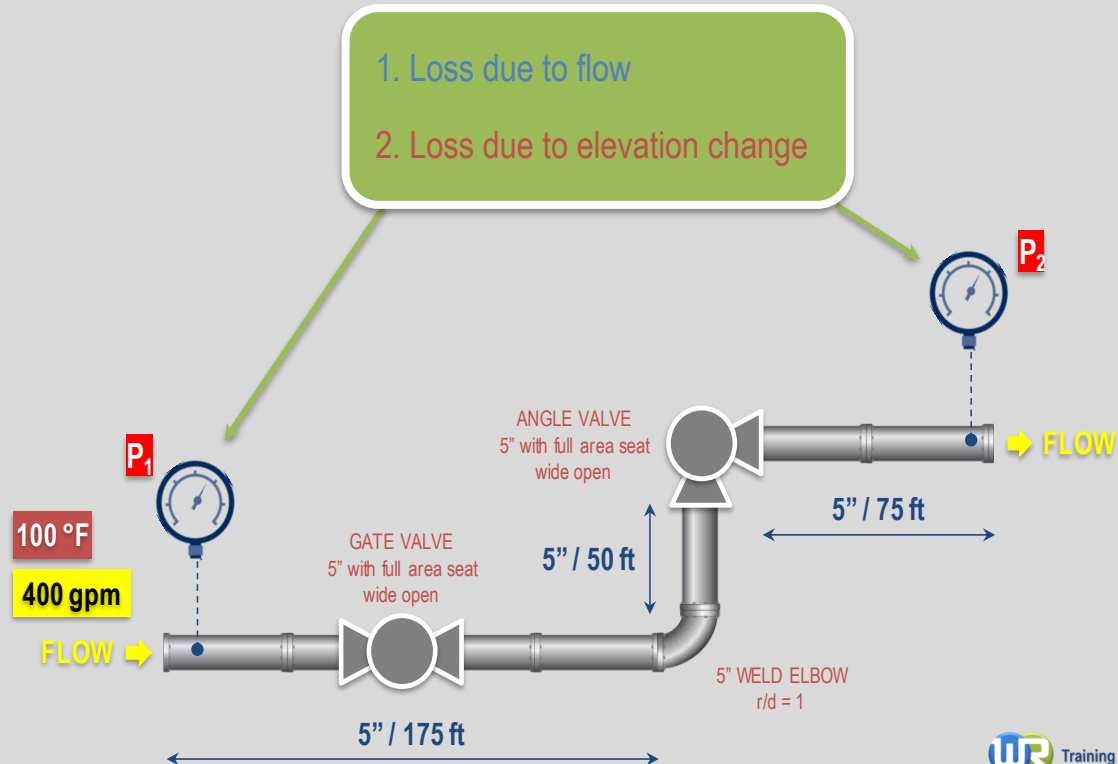
Oil dynamic viscosity at 100°F (μ_{oil}) : 130 cP

Oil weight density at 100°F (ρ_{oil}) : 54.26 lb/ft³

Rate of flow : 400 gpm

$$\Delta P = 1.801 \times 10^{-5} \frac{K \rho Q^2}{d^2}$$

$$\Delta P = \frac{h_L \rho}{144}$$



Pipe internal diameter (d_2) : 5.047 in

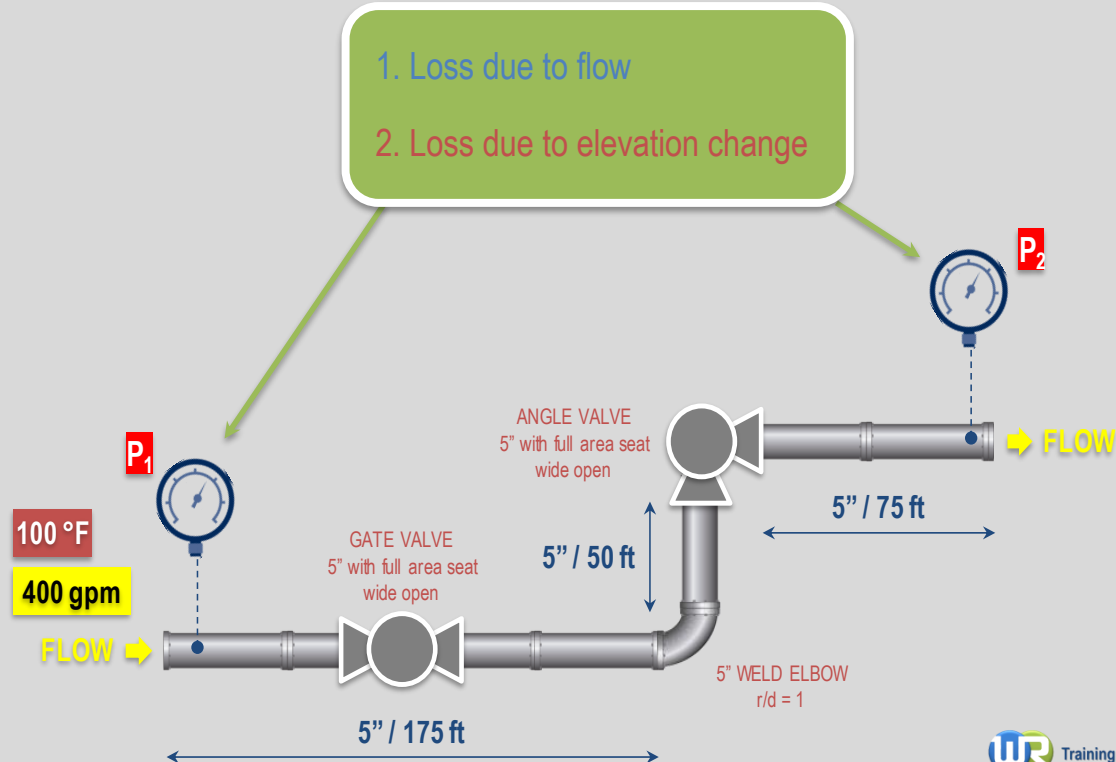
Oil dynamic viscosity at 100°F (μ_{oil}) : 130 cP

Oil weight density at 100°F (ρ_{oil}) : 54.26 lb/ft³

Rate of flow : 400 gpm

Elevation change (ΔP_1) : 18.84 psi

$$\Delta P = \frac{h_L \rho}{144}$$



Pipe internal diameter (d_2) : 5.047 in

Oil dynamic viscosity at 100°F (μ_{oil}) : 130 cP

Oil weight density at 100°F (ρ_{oil}) : 54.26 lb/ft³

Rate of flow : 400 gpm

$$f = \frac{64}{Re} = \frac{64\mu}{124dv\rho}$$

Reynolds number (Re) :

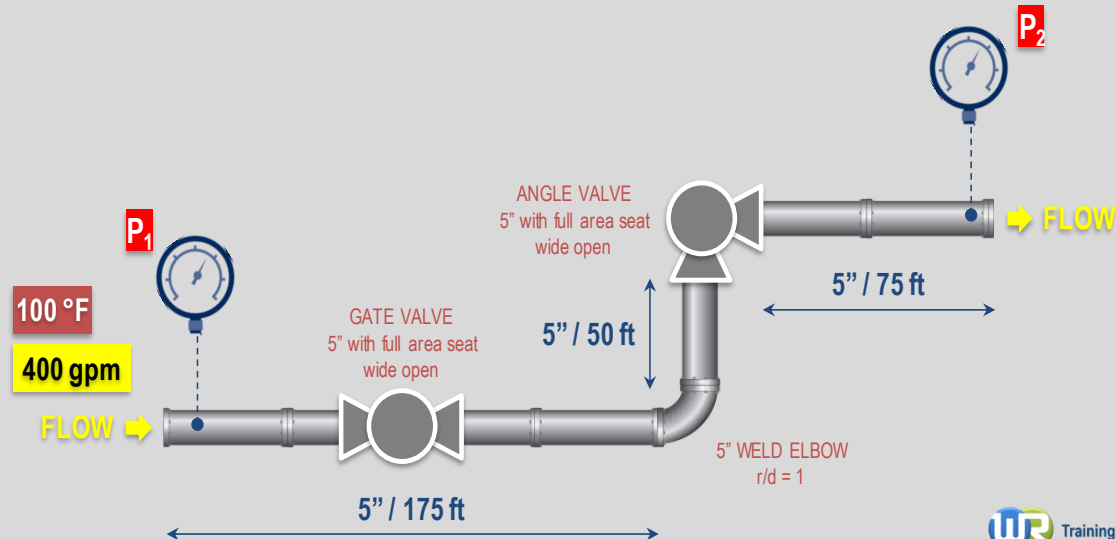
Nature of flow in pipe :

LAMINAR FLOW

Pipe friction factor (f) : 0.038

Pipe resistance coefficient (K_1) :

$$\Delta P = 1.801 \times 10^{-5} \frac{K\rho Q^2}{d^2}$$



Pipe internal diameter (d_2) : 5.047 in

Oil dynamic viscosity at 100°F (μ_{oil}) : 130 cP

Oil weight density at 100°F (ρ_{oil}) : 54.26 lb/ft³

Rate of flow : 400 gpm

$$K = f \frac{L}{D}$$

Reynolds number (Re) : 1675

Nature of flow in pipe :

LAMINAR FLOW

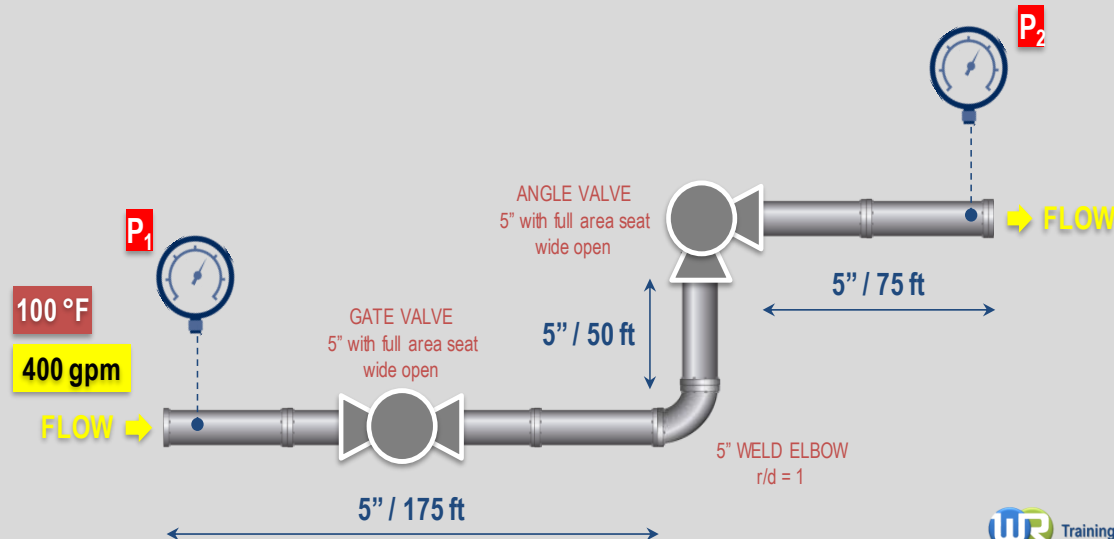
Pipe friction factor (f) : 0.038

Pipe resistance coefficient (K_1) : 27.10

G. Valve resistance coefficient (K_2) : 0.12

A. Valve resistance coefficient (K_3) : 2.25

Elbow resistance coefficient (K_4) : 0.3



Pipe internal diameter (d_2) : 5.047 in

Oil dynamic viscosity at 100°F (μ_{oil}) : 130 cP

Oil weight density at 100°F (ρ_{oil}) : 54.26 lb/ft³

Rate of flow : 400 gpm

Reynolds number (Re) : 1675

Nature of flow in pipe :

LAMINAR FLOW

Pipe friction factor (f) : 0.038

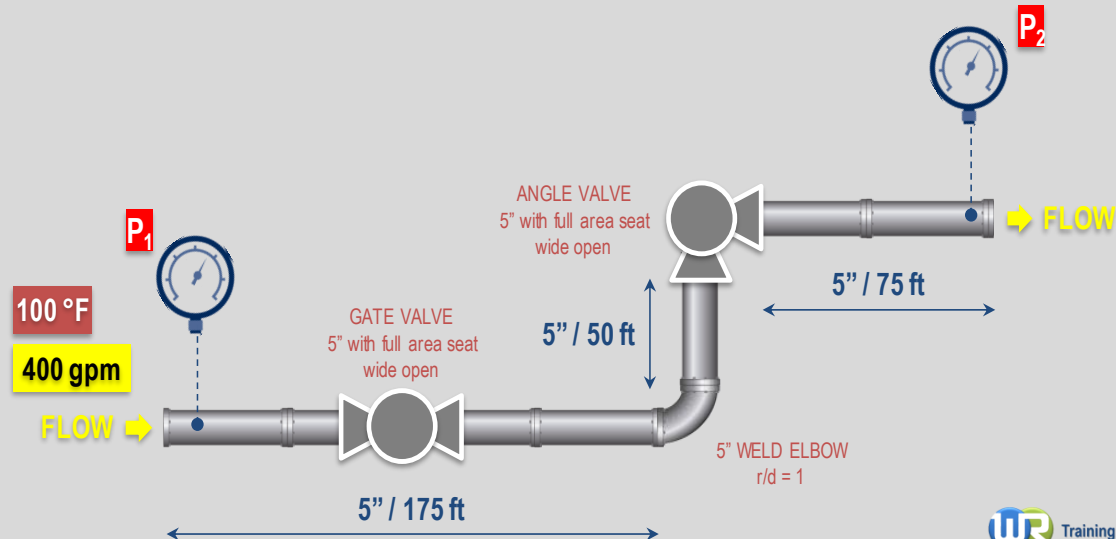
Pipe resistance coefficient (K_1) : 27.10

G. Valve resistance coefficient (K_2) : 0.12

A. Valve resistance coefficient (K_3) : 2.25

Elbow resistance coefficient (K_4) : 0.3

System resistance coefficient (K_T) : 29.77



Pipe internal diameter (d_2) : 5.047 in

Oil dynamic viscosity at 100°F (μ_{oil}) : 130 cP

Oil weight density at 100°F (ρ_{oil}) : 54.26 lb/ft³

Rate of flow : 400 gpm

System resistance coefficient (K_T) : 29.77

$$\Delta P = 1.801 \times 10^{-5} \frac{K \rho Q^2}{d^2} = 7.17 \text{ psi}$$

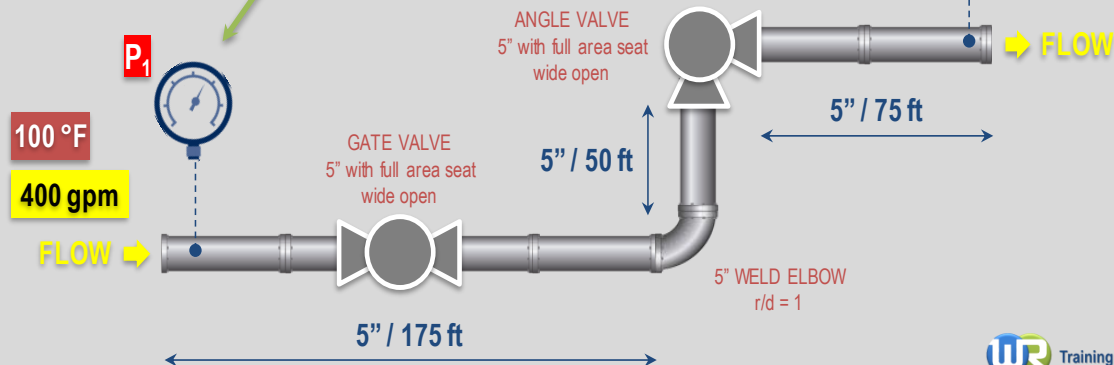
$$\Delta P = \frac{h_L \rho}{144} = 18.84 \text{ psi}$$

1. Loss due to flow

= 7.17 psi

2. Loss due to elevation change

= 18.84 psi



Pipe internal diameter (d_2) : 5.047 in

Oil dynamic viscosity at 100°F (μ_{oil}) : 130 cP

Oil weight density at 100°F (ρ_{oil}) : 54.26 lb/ft³

Rate of flow : 400 gpm

System resistance coefficient (K_T) : 29.77

$$\Delta P = 1.801 \times 10^{-5} \frac{K \rho Q^2}{d^2} = 7.17 \text{ psi}$$

$$\Delta P = \frac{h_L \rho}{144} = 18.84 \text{ psi}$$

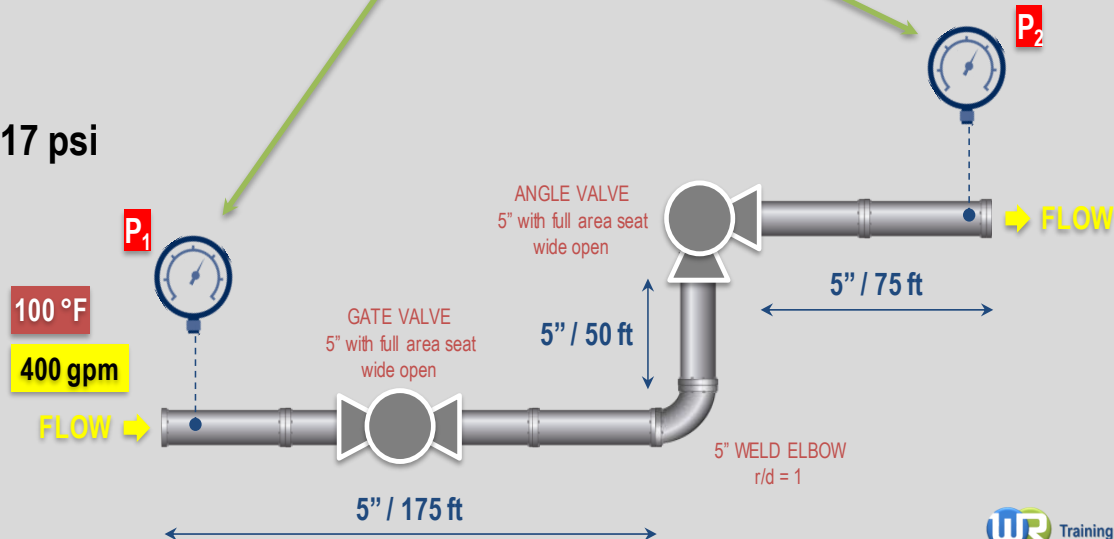
26 psi

1. Loss due to flow

= 7.17 psi

2. Loss due to elevation change

= 18.84 psi

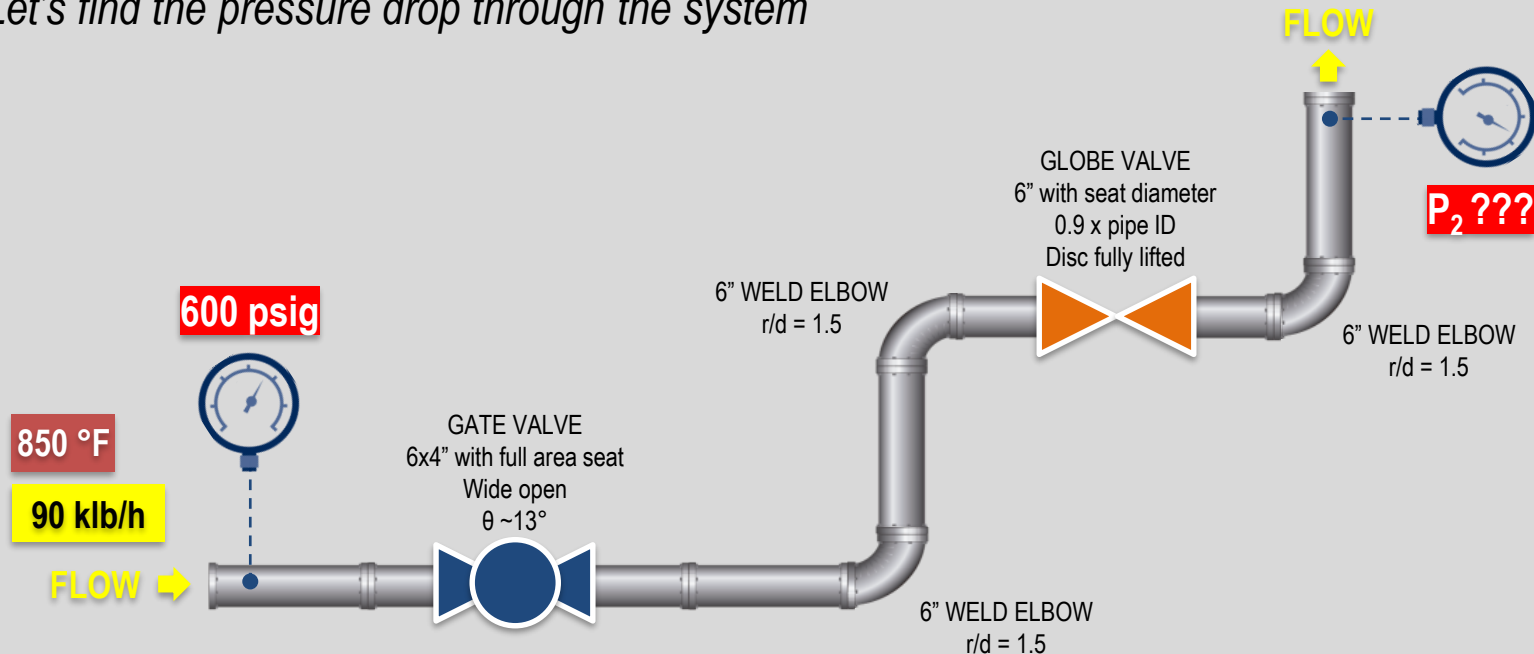


CONCRETE EXAMPLE # 9

**PRESSURE DROP
THROUGH PIPING SYSTEM
SUPERHEATED STEAM
TURBULENT FLOW**

- ▶ 600 psig steam at 850°F flows through 400 ft of horizontal 6" schedule 80 pipe at a rate of 90000 lb/h as depicted in the following figure.

Let's find the pressure drop through the system



Pipe internal diameter (d_2) : 5.761 in

Gate valve exit internal diameter (d'_2) : 3.826 in

Globe valve internal diameter (d_1) : 5.185 in (= 0.9 x d_2)

Steam dynamic viscosity at 850°F (μ) : 0.027 cP

Steam specific volume at 850°F (ρ) : 1.2 ft³/lb

Rate of flow : 90 klb/h

Reynolds number (Re) :

Pipe friction factor (f) :

Nature of flow in pipe :

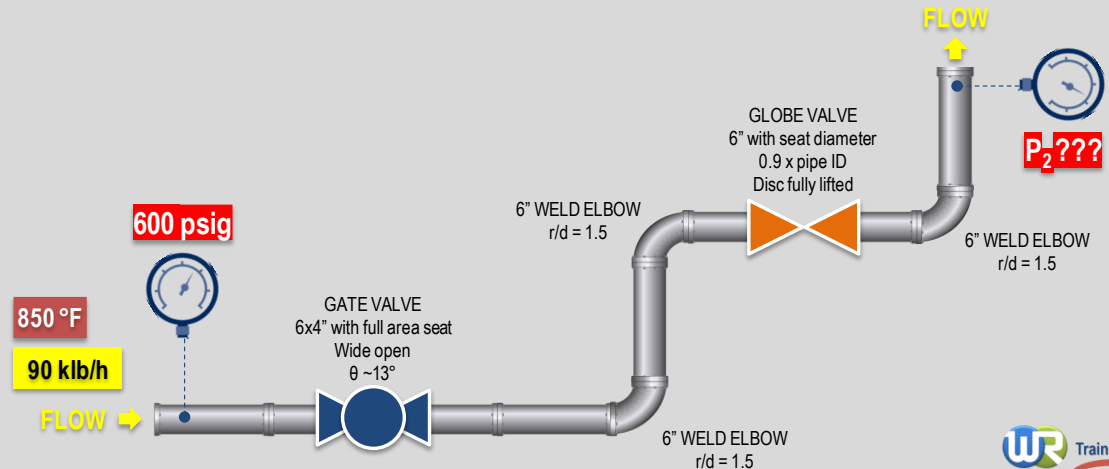
TURBULENT FLOW

Gate valve resistance coefficient (K_1) :

Globe valve resistance coefficient (K_2) :

Elbows resistance coefficient (K_3) :

Pipe resistance coefficient (K_4) :



Pipe internal diameter (d_2) : 5.761 in

Gate valve exit internal diameter (d'_2) : 3.826 in

Globe valve internal diameter (d_1) : 5.185 in (= 0.9 x d_2)

Steam dynamic viscosity at 850°F (μ) : 0.027 cP

Steam specific volume at 850°F (ρ) : 1.2 ft³/lb

Rate of flow : 90 klb/h

$$K = f \frac{L}{D}$$

Nature of flow in pipe :

TURBULENT FLOW

Reynolds number (Re) : 3.65×10^6

Pipe friction factor (f) : 0.015

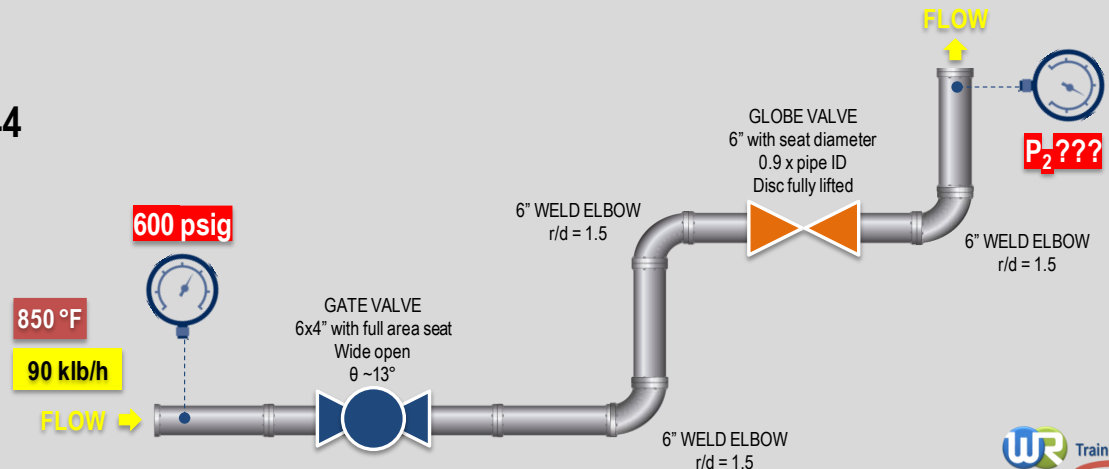
Gate valve resistance coefficient (K_1) : 1.35

Globe valve resistance coefficient (K_2) : 1.44

Elbows resistance coefficient (K_3) : 0.63

Pipe resistance coefficient (K_4) :

System resistance coefficient (K_T) : 15.92



Pipe internal diameter (d_2) : 5.761 in

Gate valve exit internal diameter (d'_2) : 3.826 in

Globe valve internal diameter (d_1) : 5.185 in ($= 0.9 \times d_2$)

Steam dynamic viscosity at 850°F (μ) : 0.027 cP

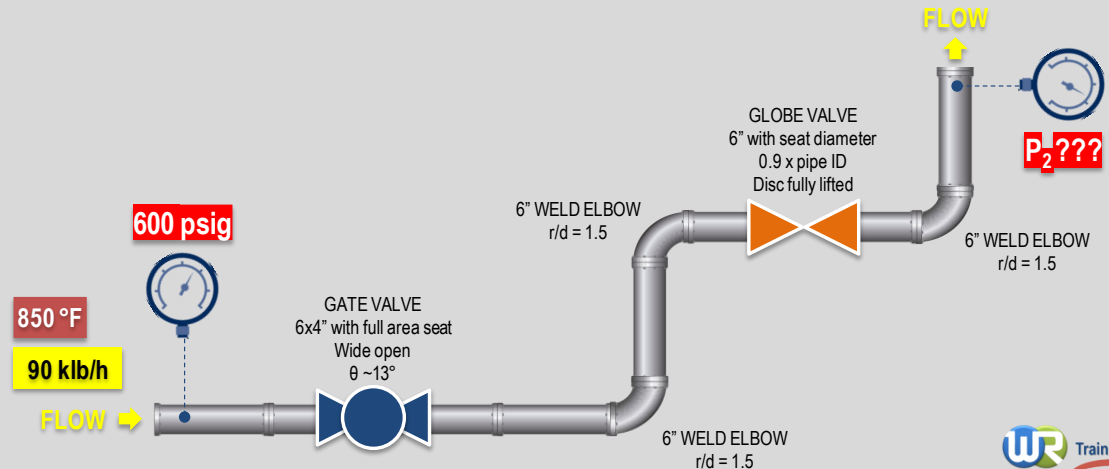
Steam specific volume at 850°F (ρ) : 1.2 ft³/lb

Rate of flow : 90 klb/h

$$\Delta P = 40 \text{ psi}$$

$$P_2 = 560 \text{ psig}$$

System resistance coefficient (K_T) : 15.92

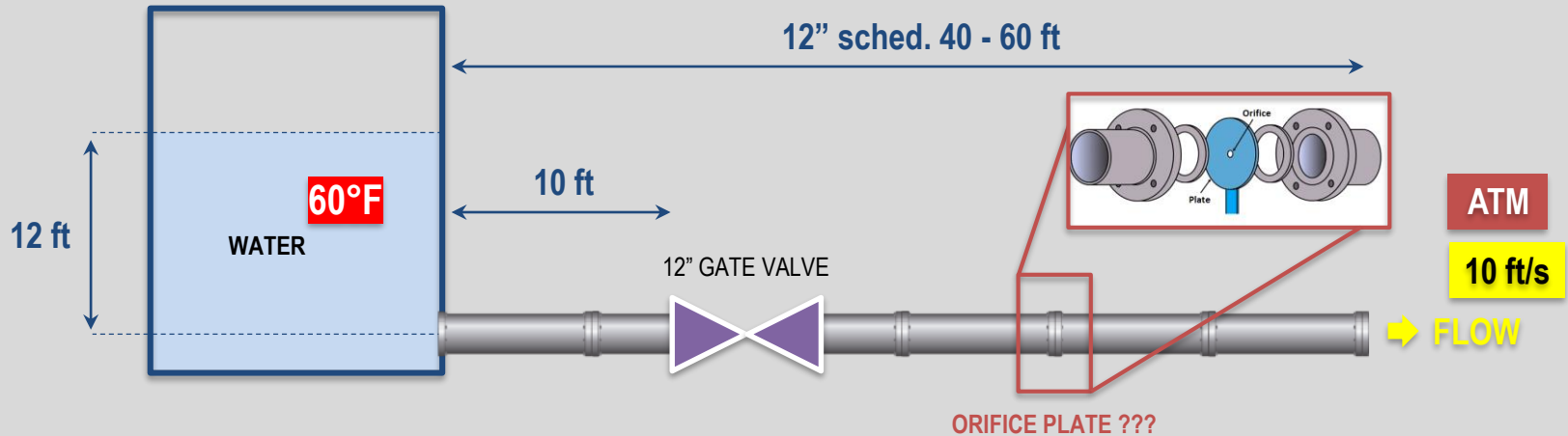


CONCRETE EXAMPLE # 10

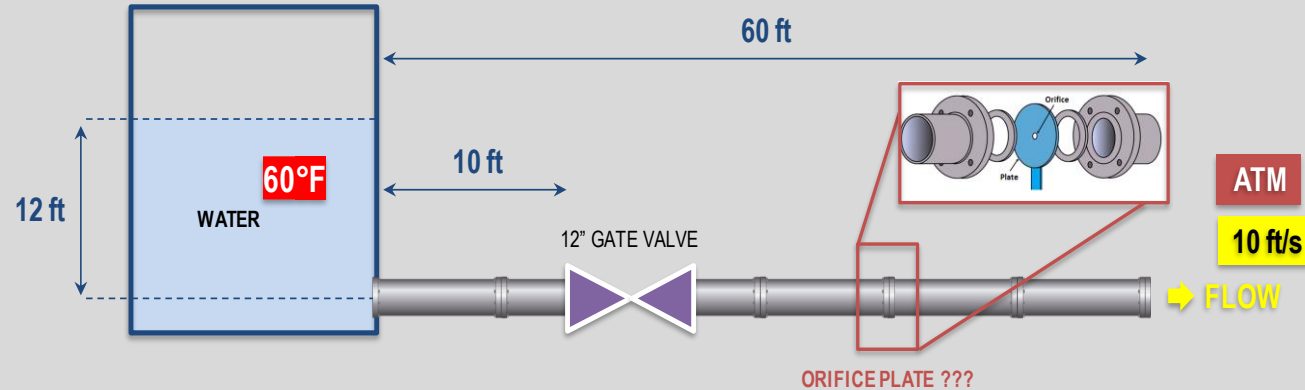
**SIZING AN ORIFICE FOR A GIVEN
PRESSURE DROP AND FLUID VELOCITY**

- ▶ A 12" schedule 40 steel pipe 60 ft long containing a standard gate valve 10 ft from the entrance, discharges 60°F water to atmosphere from a reservoir as depicted in the following figure.

Let's find the diameter of thin-plate orifice to be installed in the pipe to restrict the velocity of flow to 10 ft/s when the gate valve is wide open



CONCRETE EXAMPLE #10



$$Re = 124 \frac{dv\rho}{\mu}$$

$$K = f \frac{L}{D}$$

Pipe length (L) : 60 ft

Pipe internal diameter (d_2) : 11.938 in

Gate valve internal diameter (d_1) : 11.938 in

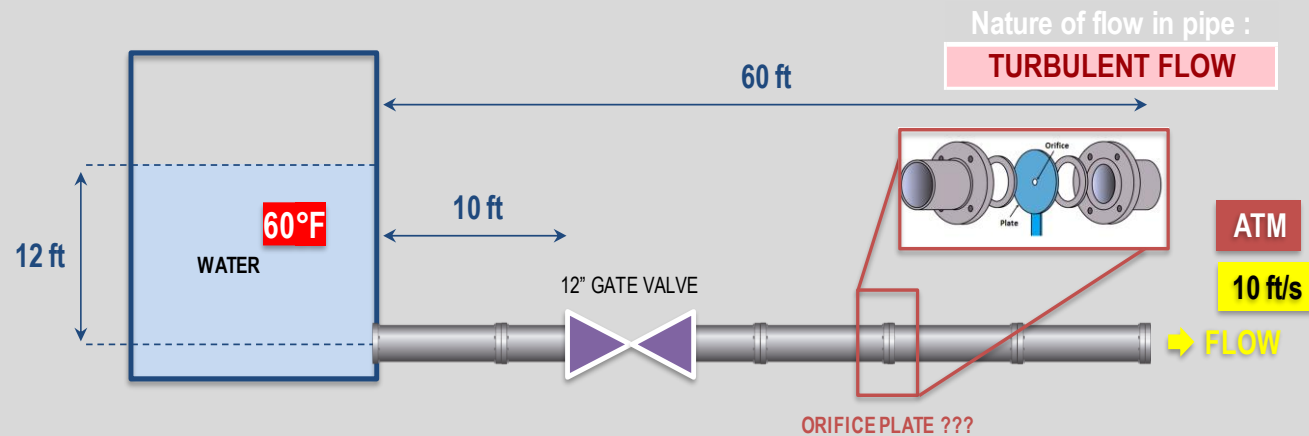
Water dynamic viscosity at 60°F (μ) : 1.1 cP

Water weight density at 60°F (ρ) : 62.364 lb/ft³

System resistance (excluding orifice) :

1. Entrance (K_1) :
2. Gate valve (K_2) :
3. Exit (K_3) :
4. Pipe (K_4) :

CONCRETE EXAMPLE #10



$$Re = 8.4 \times 10^5$$

$$K = f \frac{L}{D}$$

Pipe length (L) : 60 ft

Pipe internal diameter (d_2) : 11.938 in

Gate valve internal diameter (d_1) : 11.938 in

Water dynamic viscosity at 60°F (μ) : 1.1 cP

Water weight density at 60°F (ρ) : 62.364 lb/ft³

System resistance (excluding orifice) :

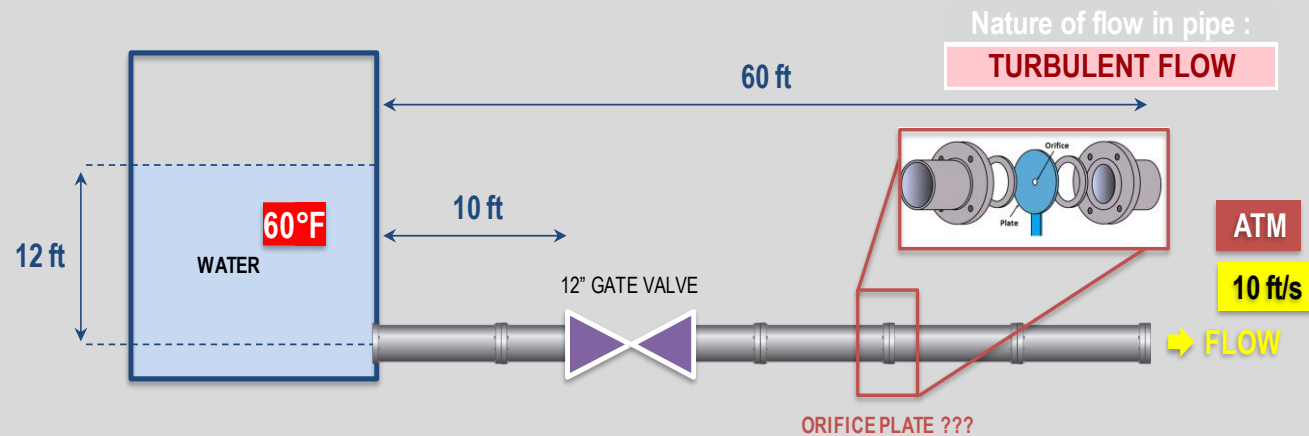
1. Entrance (K_1) : 0.78

2. Gate valve (K_2) : 0.1

3. Exit (K_3) : 1

4. Pipe (K_4) :

CONCRETE EXAMPLE #10



$$h_L = K \frac{v^2}{2g}$$

Pipe length (L) : 60 ft

Pipe internal diameter (d_2) : 11.938 in

Gate valve internal diameter (d_1) : 11.938 in

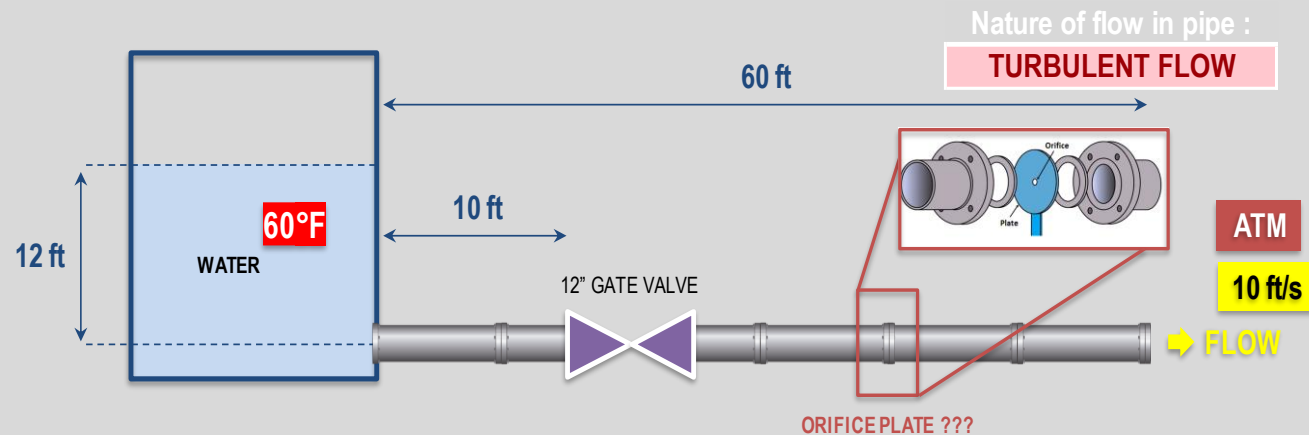
Water dynamic viscosity at 60°F (μ) : 1.1 cP

Water weight density at 60°F (ρ) : 62.364 lb/ft³

System resistance (excluding orifice) :

System resistance (including orifice) :

CONCRETE EXAMPLE #10



$$K = \frac{2gh_L}{v^2}$$

Pipe length (L) : 60 ft

Pipe internal diameter (d_2) : 11.938 in

Gate valve internal diameter (d_1) : 11.938 in

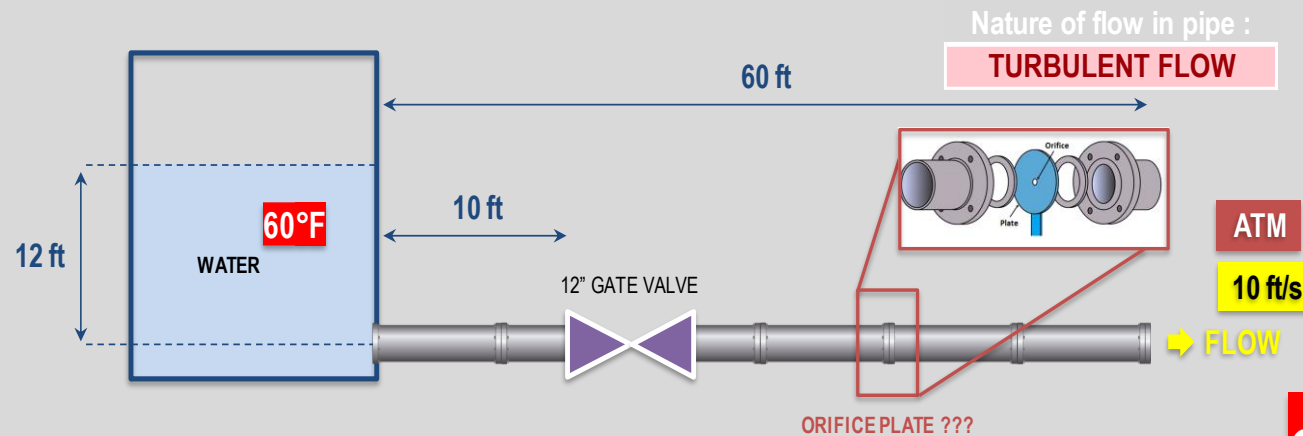
Water dynamic viscosity at 60°F (μ) : 1.1 cP

Water weight density at 60°F (ρ) : 62.364 lb/ft³

System resistance (excluding orifice) : 2.6

System resistance (including orifice) :

Orifice resistance coefficient (K_{orifice}) : 5.12



$$d_{\text{orifice}} = 11.938 \times \beta$$

Pipe length (L) : 60 ft

Pipe internal diameter (d_2) : 11.938 in

Gate valve internal diameter (d_1) : 11.938 in

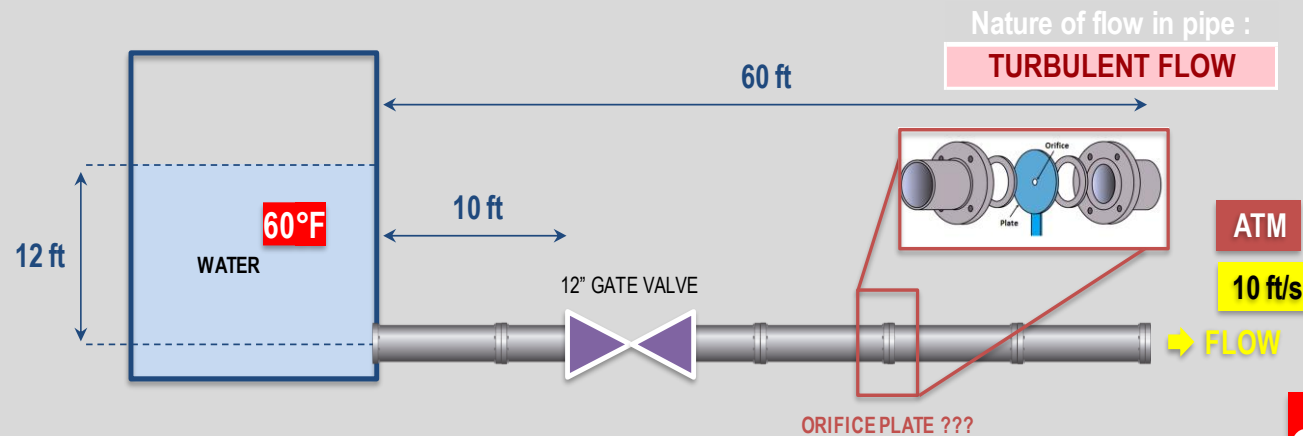
Water dynamic viscosity at 60°F (μ) : 1.1 cP

Water weight density at 60°F (ρ) : 62.364 lb/ft³

Orifice resistance coefficient (K_{orifice}) : 5.12

1. Assume a value for $\beta = d_{\text{orifice}} / 11.938$
2. Determine associated C based on β & Re
3. Calculate associated K_{orifice}

CONCRETE EXAMPLE #10



$$d_{\text{orifice}} = 11.938 \times \beta$$

Pipe length (L) : 60 ft

Pipe internal diameter (d_2) : 11.938 in

Gate valve internal diameter (d_1) : 11.938 in

Water dynamic viscosity at 60°F (μ) : 1.1 cP

Water weight density at 60°F (ρ) : 62.364 lb/ft³

Orifice resistance coefficient (K_{orifice}) : 5.12

Correct assumption → β : 0.686

$$d_{\text{orifice}} = 8.19''$$

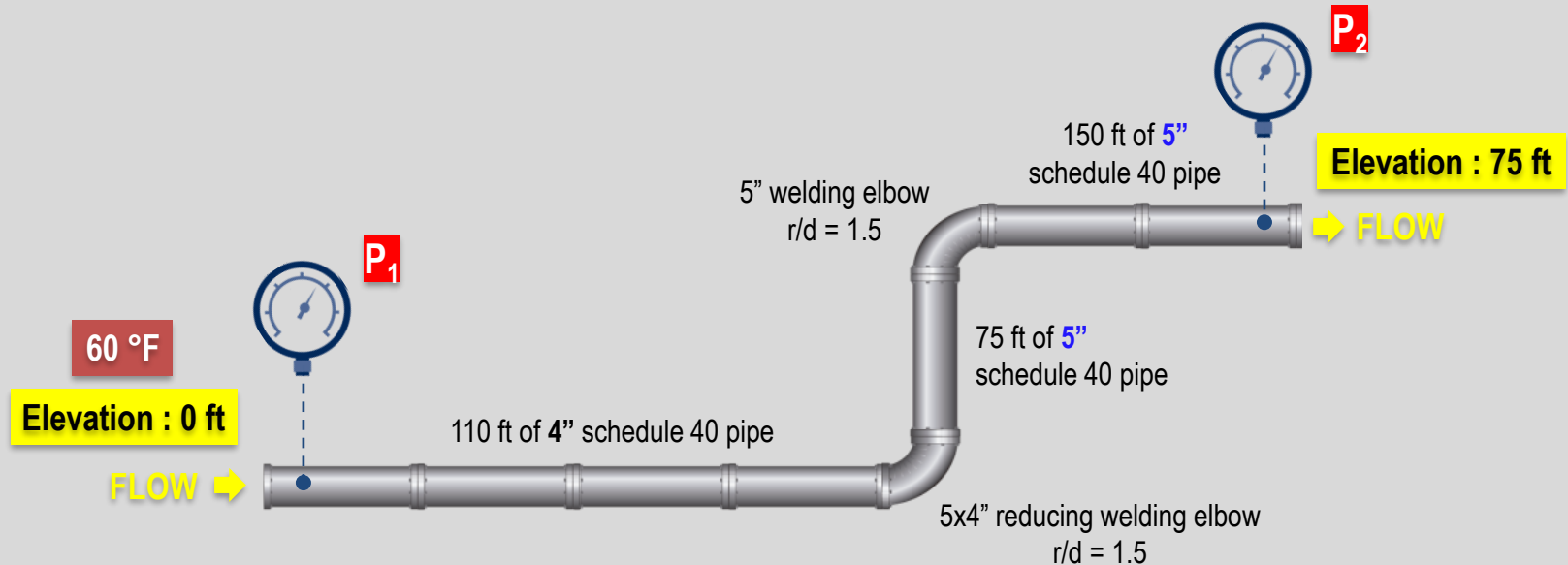
CONCRETE EXAMPLE # 11

BERNOULLI'S THEOREM

PRESSURE DROP AND FLUID VELOCITY

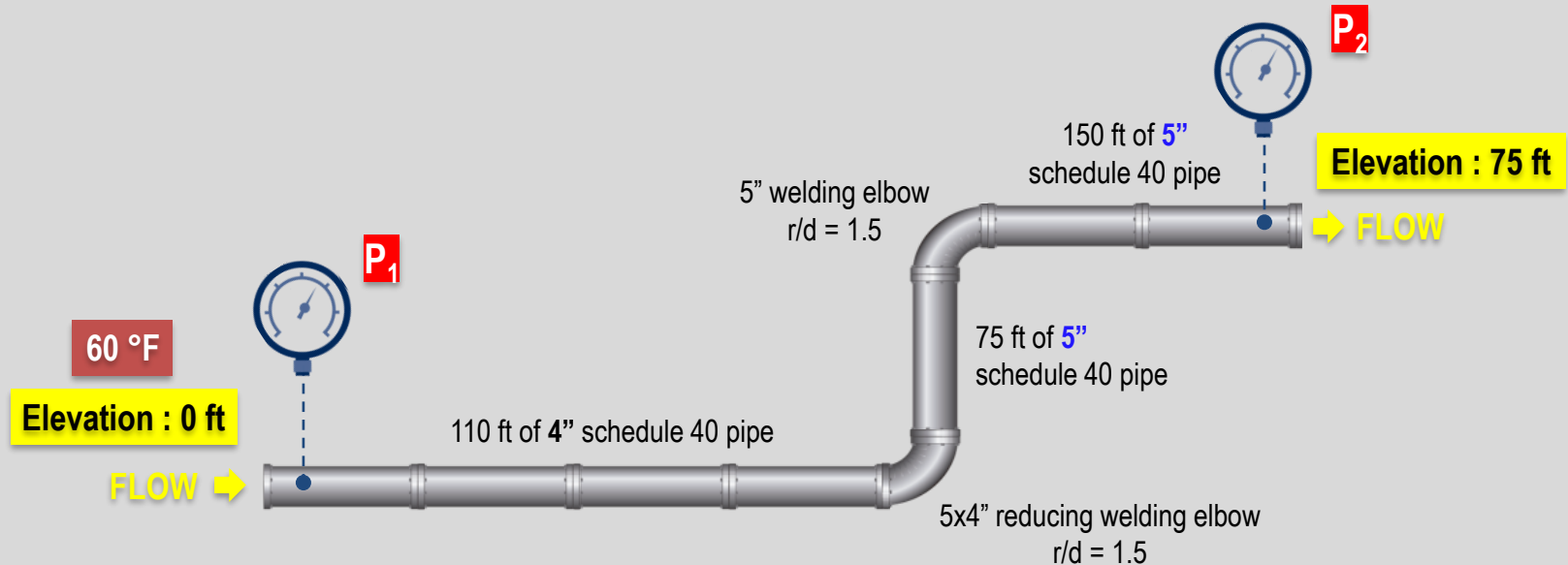
- Water at 60°F flows through the piping system as depicted below at a rate of 400 gpm.

Let's find the velocity in both the 4" and 5" pipe sizes and the pressure drop through the system



- Water at 60°F flows through the piping system as depicted below at a rate of 400 gpm.

Let's find the velocity in both the 4" and 5" pipe sizes and the pressure drop through the system



4" Pipe internal diameter : 4.026 in

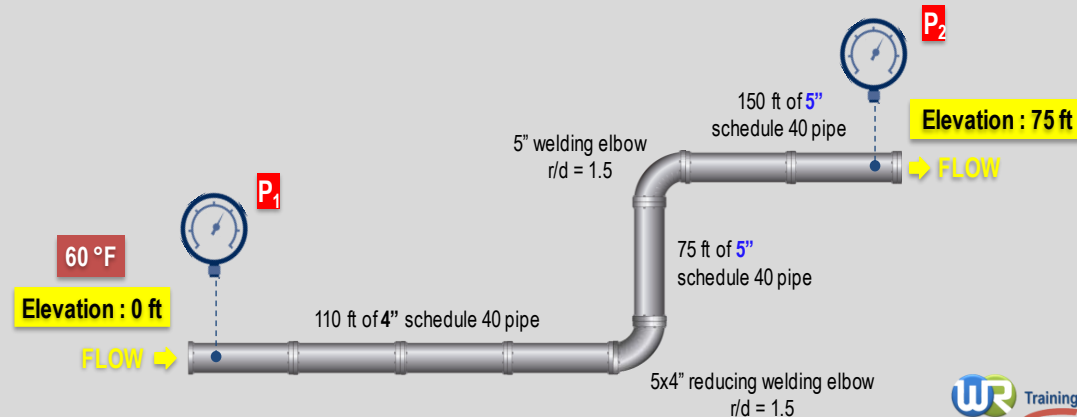
5" Pipe internal diameter : 5.047 in

Water weight density at 60°F (ρ) : 62.364 lb/ft³

Water dynamic viscosity at 60°F (μ) : 1.1 cP

Rate of flow : 400 gpm = 0.8912 ft³/s

$$Z_1 + \frac{144 P_1}{\rho} + \frac{v_1^2}{2g} = Z_2 + \frac{144 P_2}{\rho} + \frac{v_2^2}{2g} + h_L$$



4" Pipe internal diameter : 4.026 in

5" Pipe internal diameter : 5.047 in

Water weight density at 60°F (ρ) : 62.364 lb/ft³

Water dynamic viscosity at 60°F (μ) : 1.1 cP

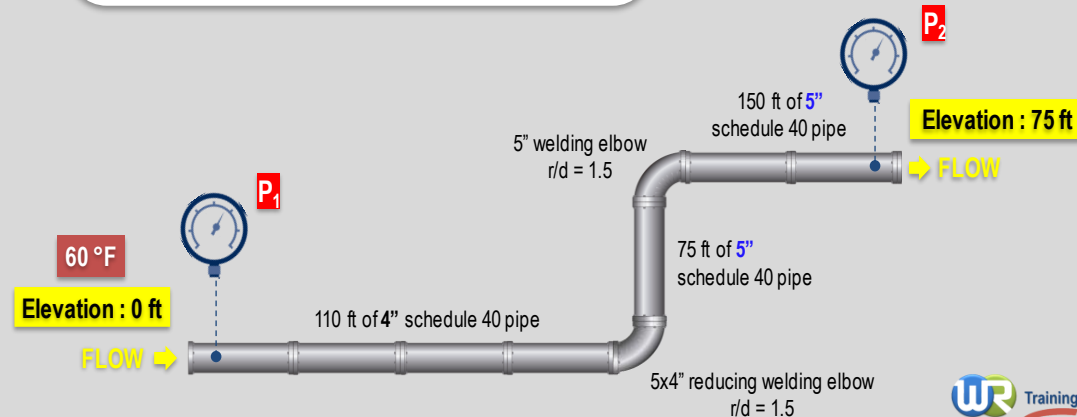
Rate of flow : 400 gpm = 0.8912 ft³/s

Velocity in 4" pipe (v₁) = 10.08 ft/s

Velocity in 5" pipe (v₂) = 6.41 ft/s

$$P_1 - P_2 = \frac{\rho}{144} \left[(Z_2 - Z_1) + \frac{v_2^2 - v_1^2}{2g} + h_L \right]$$

$$h_L = 0.002593 \frac{KQ^2}{d^4}$$



4" Pipe internal diameter : 4.026 in

5" Pipe internal diameter : 5.047 in

Water weight density at 60°F (ρ) : 62.364 lb/ft³

Water dynamic viscosity at 60°F (μ) : 1.1 cP

Rate of flow : 400 gpm = 0.8912 ft³/s

Velocity in 4" pipe (v_1) = 10.08 ft/s

Velocity in 5" pipe (v_2) = 6.41 ft/s

Reynolds number in 4" pipe (Re_1) : 2.85×10^5

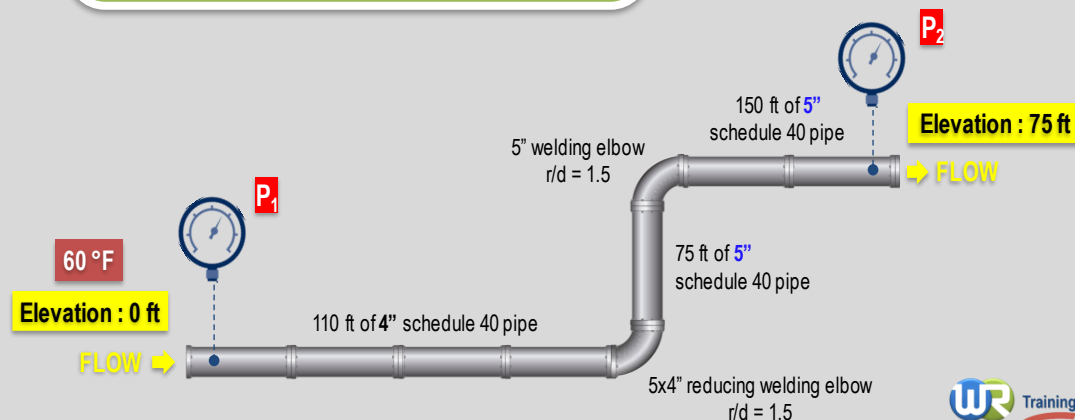
Reynolds number in 5" pipe (Re_2) : 2.27×10^5

Friction factor in 4" pipe (f_1) : ~0.018

Friction factor in 5" pipe (f_2) : ~0.018

$$P_1 - P_2 = \frac{\rho}{144} \left[(Z_2 - Z_1) + \frac{v_2^2 - v_1^2}{2g} + h_L \right]$$

$$K = f \frac{L}{D}$$



4" Pipe internal diameter : 4.026 in

5" Pipe internal diameter : 5.047 in

Water weight density at 60°F (ρ) : 62.364 lb/ft³

Water dynamic viscosity at 60°F (μ) : 1.1 cP

Rate of flow : 400 gpm = 0.8912 ft³/s

$$P_1 - P_2 = \frac{\rho}{144} \left[(Z_2 - Z_1) + \frac{v_2^2 - v_1^2}{2g} + h_L \right]$$

$$K = f \frac{L}{D}$$

Velocity in 4" pipe (v_1) = 10.08 ft/s

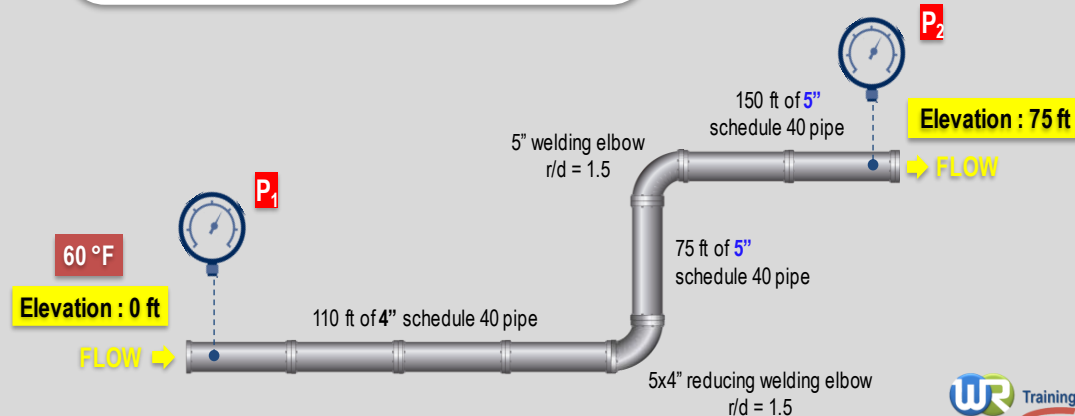
Velocity in 5" pipe (v_2) = 6.41 ft/s

Friction factor in 4" pipe (f_1) : ~0.018

Friction factor in 5" pipe (f_2) : ~0.018

4" pipe resistance coefficient (K_1) : 5.9

5" pipe resistance coefficient (K_2) : 9.6



4" Pipe internal diameter : 4.026 in

5" Pipe internal diameter : 5.047 in

Water weight density at 60°F (ρ) : 62.364 lb/ft³

Water dynamic viscosity at 60°F (μ) : 1.1 cP

Rate of flow : 400 gpm = 0.8912 ft³/s

$$P_1 - P_2 = \frac{\rho}{144} \left[(Z_2 - Z_1) + \frac{v_2^2 - v_1^2}{2g} + h_L \right]$$

$$K = f \frac{L}{D}$$

Velocity in 4" pipe (v_1) = 10.08 ft/s

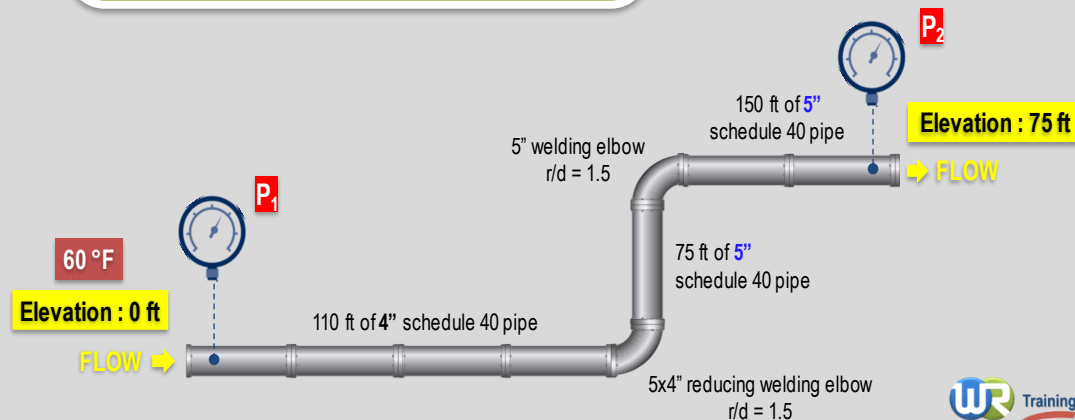
Velocity in 5" pipe (v_2) = 6.41 ft/s

Friction factor in 4" pipe (f_1) : ~0.018

Friction factor in 5" pipe (f_2) : ~0.018

4" pipe resistance coefficient (K_1) : 5.9

5" pipe resistance coefficient (K_2) : 9.6



4" Pipe internal diameter : 4.026 in

5" Pipe internal diameter : 5.047 in

Water weight density at 60°F (ρ) : 62.364 lb/ft³

Water dynamic viscosity at 60°F (μ) : 1.1 cP

Rate of flow : 400 gpm = 0.8912 ft³/s

Velocity in 4" pipe (v_1) = 10.08 ft/s

Velocity in 5" pipe (v_2) = 6.41 ft/s

Friction factor in 4" pipe (f_1) : ~0.018

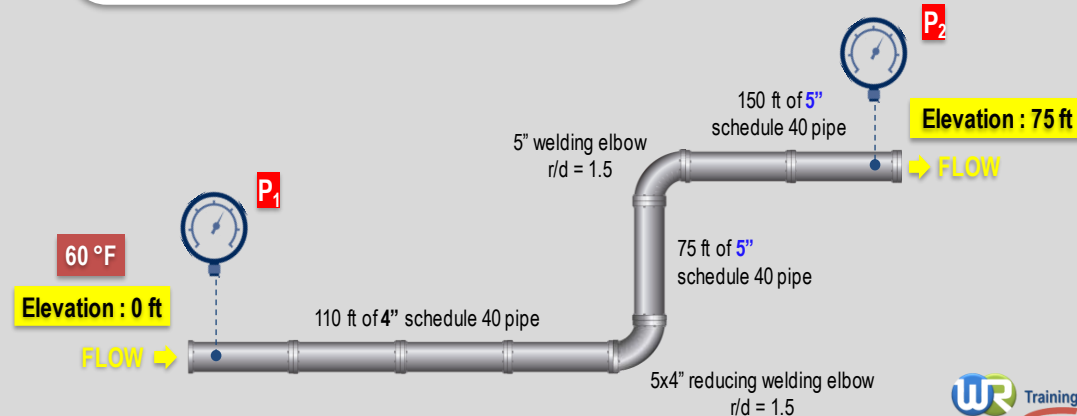
Friction factor in 5" pipe (f_2) : ~0.018

4" pipe resistance coefficient (K_1) : 5.9

5" pipe resistance coefficient (K_2) : 9.6

$$P_1 - P_2 = \frac{\rho}{144} \left[(Z_2 - Z_1) + \frac{v_2^2 - v_1^2}{2g} + h_L \right]$$

$$K_{4" \text{ to } 5"} = \frac{K_{4"}}{\beta^4}$$



4" Pipe internal diameter : 4.026 in

5" Pipe internal diameter : 5.047 in

Water weight density at 60°F (ρ) : 62.364 lb/ft³

Water dynamic viscosity at 60°F (μ) : 1.1 cP

Rate of flow : 400 gpm = 0.8912 ft³/s

Velocity in 4" pipe (v_1) = 10.08 ft/s

Velocity in 5" pipe (v_2) = 6.41 ft/s

Friction factor in 4" pipe (f_1) : ~0.018

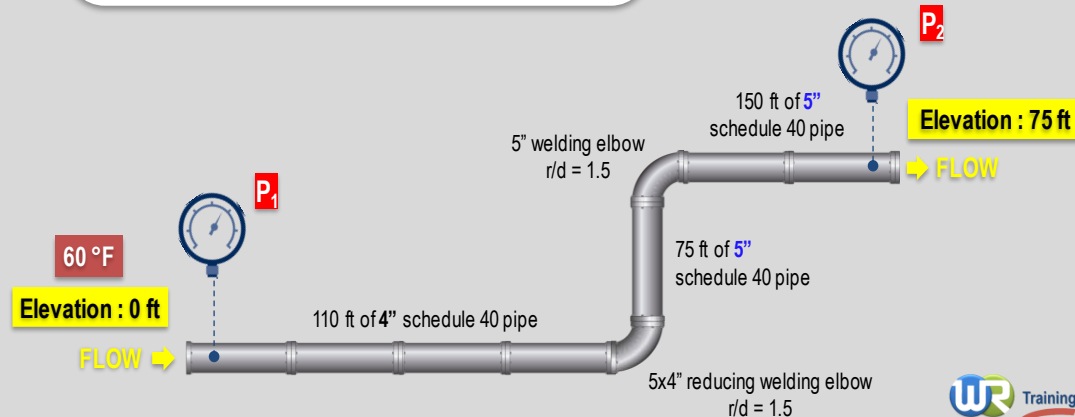
Friction factor in 5" pipe (f_2) : ~0.018

4" pipe resistance coefficient (K_1) : 5.9

5" pipe resistance coefficient (K_2) : 9.6

$$P_1 - P_2 = \frac{\rho}{144} \left[(Z_2 - Z_1) + \frac{v_2^2 - v_1^2}{2g} + h_L \right]$$

$$K_{4" \text{ to } 5"} = \frac{5.9}{0.8^4}$$



4" Pipe internal diameter : 4.026 in

5" Pipe internal diameter : 5.047 in

Water weight density at 60°F (ρ) : 62.364 lb/ft³

Water dynamic viscosity at 60°F (μ) : 1.1 cP

Rate of flow : 400 gpm = 0.8912 ft³/s

Velocity in 4" pipe (v_1) = 10.08 ft/s

Velocity in 5" pipe (v_2) = 6.41 ft/s

Friction factor in 4" pipe (f_1) : ~0.018

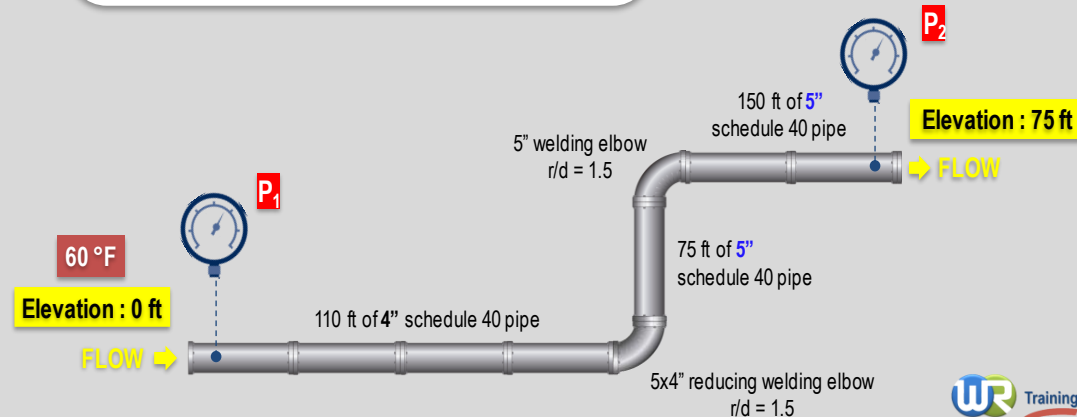
Friction factor in 5" pipe (f_2) : ~0.018

4" pipe resistance coefficient (K_1) : 14.4

5" pipe resistance coefficient (K_2) : 9.6

$$P_1 - P_2 = \frac{\rho}{144} \left[(Z_2 - Z_1) + \frac{v_2^2 - v_1^2}{2g} + h_L \right]$$

$$K_{4" \text{ to } 5"} = \frac{5.9}{0.8^4}$$



4" Pipe internal diameter : 4.026 in

5" Pipe internal diameter : 5.047 in

Water weight density at 60°F (ρ) : 62.364 lb/ft³

Water dynamic viscosity at 60°F (μ) : 1.1 cP

Rate of flow : 400 gpm = 0.8912 ft³/s

$$P_1 - P_2 = \frac{\rho}{144} \left[(Z_2 - Z_1) + \frac{v_2^2 - v_1^2}{2g} + h_L \right]$$

Velocity in 4" pipe (v_1) = 10.08 ft/s

Velocity in 5" pipe (v_2) = 6.41 ft/s

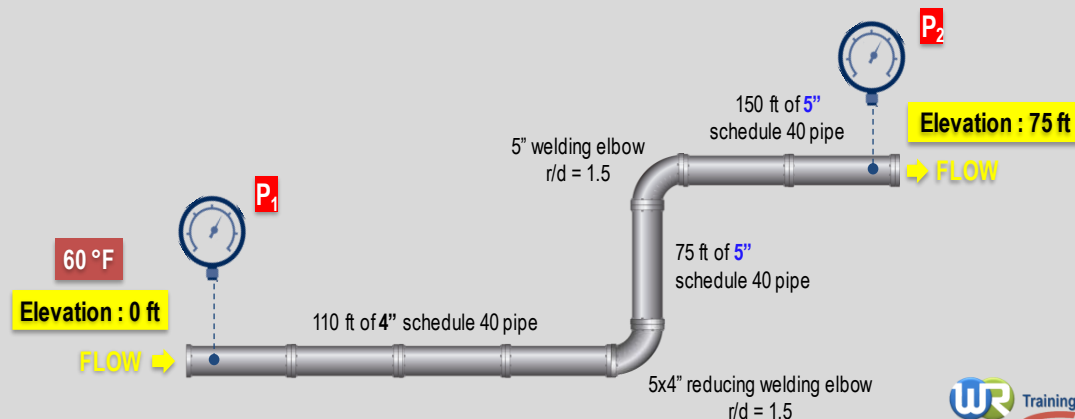
4" pipe resistance coefficient (K_1) : 14.4

5" pipe resistance coefficient (K_2) : 9.6

5" Elbows resistance coefficient (K_3) : 0.21

5x4" Reduction (K_4) : 0.31

$$K_{\text{total}} = K_1 + K_2 + 2 \times K_3 + K_4$$



4" Pipe internal diameter : 4.026 in

5" Pipe internal diameter : 5.047 in

Water weight density at 60°F (ρ) : 62.364 lb/ft³

Water dynamic viscosity at 60°F (μ) : 1.1 cP

Rate of flow : 400 gpm = 0.8912 ft³/s

$$P_1 - P_2 = \frac{\rho}{144} \left[(Z_2 - Z_1) + \frac{v_2^2 - v_1^2}{2g} + h_L \right]$$

Velocity in 4" pipe (v_1) = 10.08 ft/s

Velocity in 5" pipe (v_2) = 6.41 ft/s

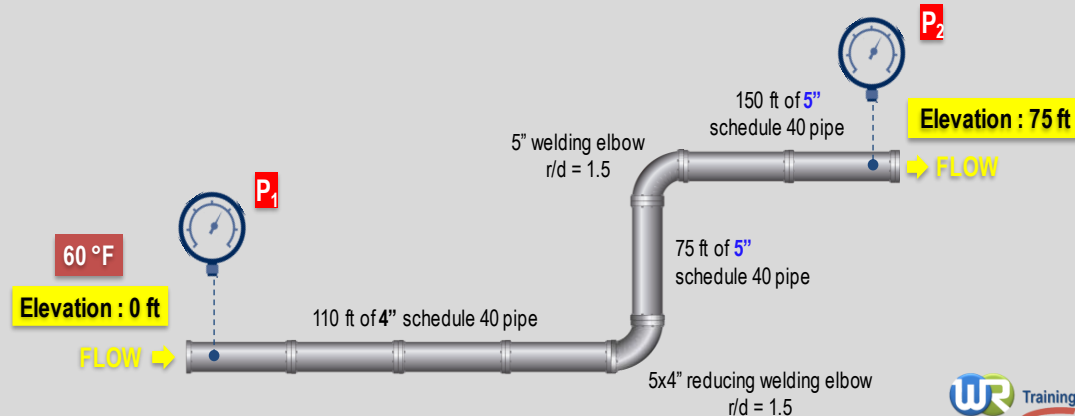
4" pipe resistance coefficient (K_1) : 14.4

5" pipe resistance coefficient (K_2) : 9.6

5" Elbows resistance coefficient (K_3) : 0.21

5x4" Reduction (K_4) : 0.31

$$K_{\text{total}} = 14.4 + 9.6 + 2 \times 0.21 + 0.31$$



4" Pipe internal diameter : 4.026 in

5" Pipe internal diameter : 5.047 in

Water weight density at 60°F (ρ) : 62.364 lb/ft³

Water dynamic viscosity at 60°F (μ) : 1.1 cP

Rate of flow : 400 gpm = 0.8912 ft³/s

$$P_1 - P_2 = \frac{\rho}{144} \left[(Z_2 - Z_1) + \frac{v_2^2 - v_1^2}{2g} + h_L \right]$$

$$K_{\text{total}} = 24.73$$

Velocity in 4" pipe (v_1) = 10.08 ft/s

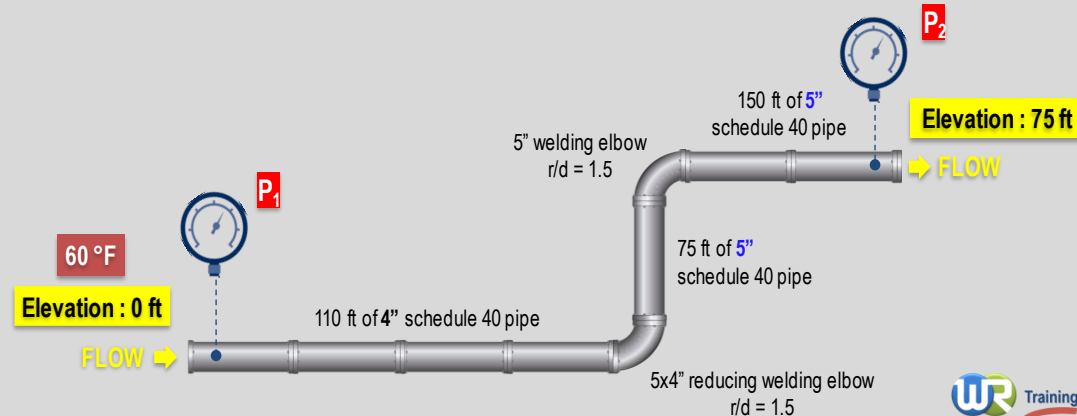
Velocity in 5" pipe (v_2) = 6.41 ft/s

4" pipe resistance coefficient (K_1) : 14.4

5" pipe resistance coefficient (K_2) : 9.6

5" Elbows resistance coefficient (K_3) : 0.21

5x4" Reduction (K_4) : 0.31



4" Pipe internal diameter : 4.026 in

5" Pipe internal diameter : 5.047 in

Water weight density at 60°F (ρ) : 62.364 lb/ft³

Water dynamic viscosity at 60°F (μ) : 1.1 cP

Rate of flow : 400 gpm = 0.8912 ft³/s

Velocity in 4" pipe (v_1) = 10.08 ft/s

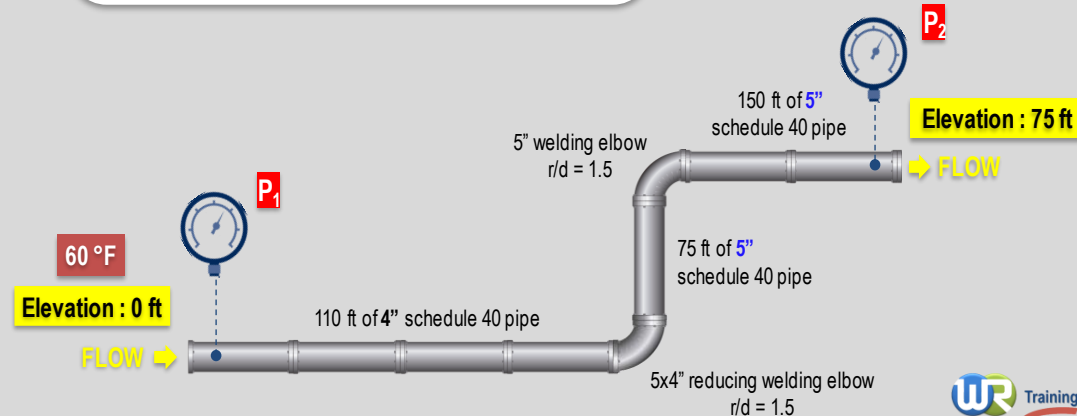
Velocity in 5" pipe (v_2) = 6.41 ft/s

System resistance coefficient (K_{total}) = 24.73

$$h_L = 15.8$$

$$P_1 - P_2 = \frac{\rho}{144} \left[(Z_2 - Z_1) + \frac{v_2^2 - v_1^2}{2g} + h_L \right]$$

$$h_L = 0.002593 \frac{KQ^2}{d^4}$$



4" Pipe internal diameter : 4.026 in

5" Pipe internal diameter : 5.047 in

Water weight density at 60°F (ρ) : 62.364 lb/ft³

Water dynamic viscosity at 60°F (μ) : 1.1 cP

Rate of flow : 400 gpm = 0.8912 ft³/s

$$P_1 - P_2 = \frac{\rho}{144} \left[(Z_2 - Z_1) + \frac{v_2^2 - v_1^2}{2g} + h_L \right]$$

$\Delta P \sim$

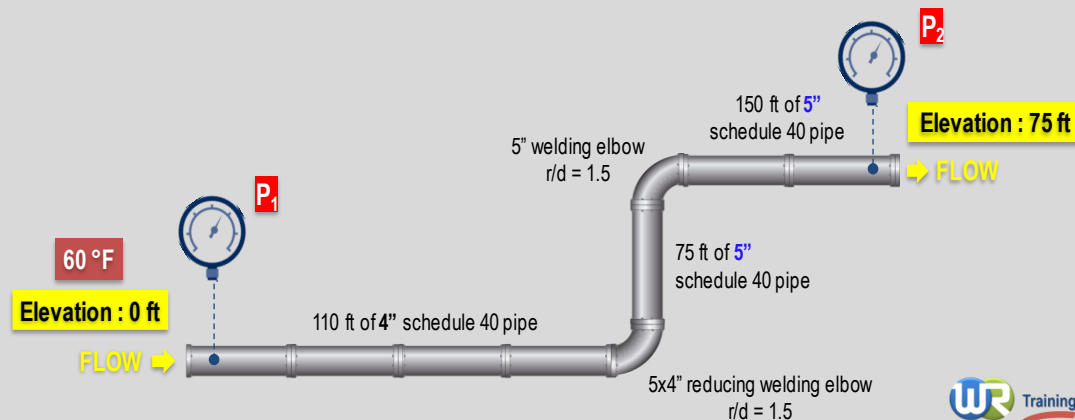
39 psi

Velocity in 4" pipe (v_1) = 10.08 ft/s

Velocity in 5" pipe (v_2) = 6.41 ft/s

System resistance coefficient (K_{total}) = 24.73

$h_L = 15.8$



CONCRETE EXAMPLE # 12

PROCESS AIR LINES

PRESSURE DROP AND VELOCITY

using Flow of Fluids Excel Workbook

- Process air at 65 psig and 110°F is flowing through 75 ft of 1" schedule 40 pipe. The rate of flow is 100 scfm.

Let's find the pressure drop and the velocity in the upstream and downstream gauges

1" Pipe internal diameter : 1.049 in

Air weight density at 110°F (ρ) : 0.378 lb/ft³

Air dynamic viscosity at 110°F (μ) : 0.0195 cP

Rate of flow : 100 scfm at 65 psig / 110°F

Pressure drop at 65 psig / 110°F = 3.48 psi/100ft

Total pressure drop = 3.48 x 75/100

- Process air at 65 psig and 110°F is flowing through 75 ft of 1" schedule 40 pipe. The rate of flow is 100 scfm.

Let's find the pressure drop and the velocity in the upstream and downstream gauges

1" Pipe internal diameter : 1.049 in

Air weight density at 110°F (ρ) : 0.378 lb/ft³

Air dynamic viscosity at 110°F (μ) : 0.0195 cP

Rate of flow : 100 scfm at 65 psig / 110°F

Pressure drop at 65 psig / 110°F = 3.48 psi/100ft

Total pressure drop = 2.61 psi

- Process air at 65 psig and 110°F is flowing through 75 ft of 1" schedule 40 pipe. The rate of flow is 100 scfm.

Let's find the pressure drop and the velocity in the upstream and downstream gauges

1" Pipe internal diameter : 1.049 in

Air weight density at 110°F (ρ) : 0.378 lb/ft³

Air dynamic viscosity at 110°F (μ) : 0.0195 cP

Rate of flow : 100 scfm at 65 psig / 110°F

$$\Delta P = 2.61 \text{ psi}$$

$$P_1 = 65 \text{ psig}$$

$$P_2 = 62.39 \text{ psig}$$

Actual flow Q_1 at **up**stream gauge pressure $P_1 = 20.2$ acfm (ft³/min)

Actual flow Q_2 at **down**stream gauge pressure $P_2 = 20.9$ acfm (ft³/min)

- ▶ Process air at 65 psig and 110°F is flowing through 75 ft of 1" schedule 40 pipe. The rate of flow is 100 scfm.

Let's find the pressure drop and the velocity in the upstream and downstream gauges

1" Pipe internal diameter : 1.049 in

Air weight density at 110°F (ρ) : 0.378 lb/ft³

Air dynamic viscosity at 110°F (μ) : 0.0195 cP

Rate of flow : 100 scfm at 65 psig / 110°F

$$\text{Velocity} = \frac{\text{Volume flow}}{\text{Area}} = \frac{Q}{\pi \left(\frac{d}{2}\right)^2}$$

Actual flow Q_1 at **up**stream gauge pressure $P_1 = 20.2$ acfm (ft³/min) ➡ **Up**stream $V_1 = 3367$ ft/min

Actual flow Q_2 at **down**stream gauge pressure $P_2 = 20.9$ acfm (ft³/min) ➡ **Down**stream $V_2 = 3483$ ft/min

CONCRETE EXAMPLE # 13

CENTRIFUGAL PUMPS

SIZING OF PUMP FOR OIL PIPELINES

- ▶ Crude oil 30° API at 15.6°C with a viscosity of 75 Universal Saybolt seconds is flowing through a 12" schedule 30 steel pipe at a rate of 1900 bbl/h. The pipeline is 50 miles long with discharge at an elevation of 2000 ft above pump inlet.

Let's find the brake horsepower of the pump assuming a pump efficiency of 67%

Pipe internal diameter : 12.09 in

Crude specific gravity (sp.gr) : 0.876

Crude weight density at 15.6°C (ρ) : 54.64 lb/ft³

Crude dynamic viscosity at 15.6°C (μ) : 12.5 cP

Rate of flow : 1900 bbl/h – 1330 gpm

Reynolds number (Re) = 24360

Nature of flow in pipe :

TURBULENT FLOW

Friction factor = 0.025

Pressure drop (ΔP) = 533.7 psi

Loss of static pressure head (h_L) = 1406.5 ft

$$\text{HEAD} = h_L + \text{Elevation change}$$

- ▶ Crude oil 30° API at 15.6°C with a viscosity of 75 Universal Saybolt seconds is flowing through a 12" schedule 30 steel pipe at a rate of 1900 bbl/h. The pipeline is 50 miles long with discharge at an elevation of 2000 ft above pump inlet.

Let's find the brake horsepower of the pump assuming a pump efficiency of 67%

Pipe internal diameter : 12.09 in

Crude specific gravity (sp.gr) : 0.876

Crude weight density at 15.6°C (ρ) : 54.64 lb/ft³

Crude dynamic viscosity at 15.6°C (μ) : 12.5 cP

Rate of flow : 1900 bbl/h – 1330 gpm

Reynolds number (Re) = 24360

Nature of flow in pipe :

TURBULENT FLOW

Friction factor = 0.025

Pressure drop (ΔP) = 533.7 psi

Loss of static pressure head (h_L) = 1406.5 ft

$$\text{HEAD} = h_L + 2000 \text{ ft}$$

- ▶ Crude oil 30° API at 15.6°C with a viscosity of 75 Universal Saybolt seconds is flowing through a 12" schedule 30 steel pipe at a rate of 1900 bbl/h. The pipeline is 50 miles long with discharge at an elevation of 2000 ft above pump inlet.

Let's find the brake horsepower of the pump assuming a pump efficiency of 67%

Pipe internal diameter : 12.09 in

Crude specific gravity (sp.gr) : 0.876

Crude weight density at 15.6°C (ρ) : 54.64 lb/ft³

Crude dynamic viscosity at 15.6°C (μ) : 12.5 cP

Rate of flow : 1900 bbl/h – 1330 gpm

Reynolds number (Re) = 24360

Nature of flow in pipe :

TURBULENT FLOW

Friction factor = 0.025

Pressure drop (ΔP) = 533.7 psi

Loss of static pressure head (h_L) = 1406.5 ft

HEAD = 3406.5 ft

bhp = 1496

CONCRETE EXAMPLE # 14

FLOW THROUGH PIPES
NATURAL GAS PIPELINE

- ▶ A natural gas pipeline made of 14" schedule 20 pipe is 100 miles long. The inlet pressure is 1300 psia, the outlet pressure is 300 psia, and the average temperature is 40°F. The gas consists of :
75% Methane (CH₄) + 21% Ethane (C₂H₆) + 4% Propane (C₃H₈)

Let's find the flow rate in millions of standard cubic feet per day (Mscfd)

$$q_s = 3.2308 \left(\frac{T_b}{P_b} \right) \left(\frac{P_1^2 - P_2^2}{L_m T_{avg} S_g} \right)^{0.5} d^{2.5}$$

WEYMOUTH

FULLY TURBULENT FLOW

$$q_s = 18.062 \left(\frac{T_b}{P_b} \right) \left(\frac{P_1^2 - P_2^2}{L_m T_{avg} S_g} \right)^{0.5} d^{2.667}$$

PANHANDLE A

PARTIALLY TURBULENT FLOW

$$q_s = 18.161 [E] \left(\frac{T_b}{P_b} \right)^{1.0788} \left(\frac{P_1^2 - P_2^2}{L_m T_{avg} S_g^{0.8539}} \right)^{0.5394} d^{2.6182}$$

q_s : Rate of flow at standard conditions (ft³/h) (scfh)
 T_b : Absolute temperature at standard conditions = 520 °R
 P_b : Absolute pressure at standard conditions = 14.7 psia
 P_1 : Absolute pressure upstream (psia)
 P_2 : Absolute pressure downstream (psia)
 L_m : Length of pipe in miles (mi)
 T_{avg} : Average temperature in degrees Rankine (°R)
 S_g : Specific gravity of gas relative to air = MW(gas)/29
 d : Pipe internal diameter (in)
 E : Efficiency factor ~0.92

- ▶ A natural gas pipeline made of 14" schedule 20 pipe is 100 miles long.
The inlet pressure is 1300 psia, the outlet pressure is 300 psia, and the average temperature is 40°F. The gas consists of :
75% Methane (CH₄) + 21% Ethane (C₂H₆) + 4% Propane (C₃H₈)

Let's find the flow rate in millions of standard cubic feet per day (Mscfd)

14" Pipe internal diameter : 13.376 in

Friction factor (f) : 0.0128 **Complete turbulence**

MW

Methane (CH₄) : 1C x 12g/mol + 4H x 1g/mol

Ethane (C₂H₆) : 2C x 12g/mol + 6H x 1g/mol

Propane (C₃H₈) : 3C x 12g/mol + 8H x 1g/mol

$$q_s = 3.2308 \left(\frac{T_b}{P_b} \right) \left(\frac{P_1^2 - P_2^2}{f L_m T_{avg} S_g} \right)^{0.5} d^{2.5}$$

WEYMOUTH

FULLY TURBULENT FLOW

$$q_s = 18.062 \left(\frac{T_b}{P_b} \right) \left(\frac{P_1^2 - P_2^2}{L_m T_{avg} S_g} \right)^{0.5} d^{2.667}$$

PANHANDLE A

PARTIALLY TURBULENT FLOW

$$q_s = 18.161 \left[E \left(\frac{T_b}{P_b} \right) \right]^{1.0788} \left(\frac{P_1^2 - P_2^2}{L_m T_{avg} S_g^{0.8539}} \right)^{0.5394} d^{2.6182}$$

- ▶ A natural gas pipeline made of 14" schedule 20 pipe is 100 miles long.
The inlet pressure is 1300 psia, the outlet pressure is 300 psia, and the average temperature is 40°F. The gas consists of :
75% Methane (CH₄) + 21% Ethane (C₂H₆) + 4% Propane (C₃H₈)

Let's find the flow rate in millions of standard cubic feet per day (Mscfd)

14" Pipe internal diameter : 13.376 in

Friction factor (f) : 0.0128 **Complete turbulence**

MW

Methane (CH₄) : 16 g/mol

Ethane (C₂H₆) : 30 g/mol

Propane (C₃H₈) : 44 g/mol

Gas = 75% x 16 + 21% x 30 + 4% x 44

$$q_s = 3.2308 \left(\frac{T_b}{P_b} \right) \left(\frac{P_1^2 - P_2^2}{f L_m T_{avg} S_g} \right)^{0.5} d^{2.5}$$

WEYMOUTH

FULLY TURBULENT FLOW

$$q_s = 18.062 \left(\frac{T_b}{P_b} \right) \left(\frac{P_1^2 - P_2^2}{L_m T_{avg} S_g} \right)^{0.5} d^{2.667}$$

PANHANDLE A

PARTIALLY TURBULENT FLOW

$$q_s = 18.161 \left[E \left(\frac{T_b}{P_b} \right) \right]^{1.0788} \left(\frac{P_1^2 - P_2^2}{L_m T_{avg} S_g^{0.8539}} \right)^{0.5394} d^{2.6182}$$

- ▶ A natural gas pipeline made of 14" schedule 20 pipe is 100 miles long.
The inlet pressure is 1300 psia, the outlet pressure is 300 psia, and the average temperature is 40°F. The gas consists of :
75% Methane (CH₄) + 21% Ethane (C₂H₆) + 4% Propane (C₃H₈)

Let's find the flow rate in millions of standard cubic feet per day (Mscfd)

14" Pipe internal diameter : 13.376 in

Friction factor (f) : 0.0128 **Complete turbulence**

MW

Methane (CH₄) : 16 g/mol

Ethane (C₂H₆) : 30 g/mol

Propane (C₃H₈) : 44 g/mol

Gas = 20.06 g/mol

$$q_s = 3.2308 \left(\frac{T_b}{P_b} \right) \left(\frac{P_1^2 - P_2^2}{f L_m T_{avg} S_g} \right)^{0.5} d^{2.5}$$

WEYMOUTH

FULLY TURBULENT FLOW

$$q_s = 18.062 \left(\frac{T_b}{P_b} \right) \left(\frac{P_1^2 - P_2^2}{L_m T_{avg} S_g} \right)^{0.5} d^{2.667}$$

PANHANDLE A

PARTIALLY TURBULENT FLOW

$$q_s = 18.161 \left[E \left(\frac{T_b}{P_b} \right) \right]^{1.0788} \left(\frac{P_1^2 - P_2^2}{L_m T_{avg} S_g^{0.8539}} \right)^{0.5394} d^{2.6182}$$

- ▶ A natural gas pipeline made of 14" schedule 20 pipe is 100 miles long.
The inlet pressure is 1300 psia, the outlet pressure is 300 psia, and the average temperature is 40°F. The gas consists of :
75% Methane (CH₄) + 21% Ethane (C₂H₆) + 4% Propane (C₃H₈)

Let's find the flow rate in millions of standard cubic feet per day (Mscfd)

14" Pipe internal diameter : 13.376 in

Friction factor (f) : 0.0128 **Complete turbulence**

MW Gas : 20.06 g/mol

$S_g = \text{MW (gas)} / \text{MW (air)}$

$$q_s = 3.2308 \left(\frac{T_b}{P_b} \right) \left(\frac{P_1^2 - P_2^2}{f L_m T_{avg} S_g} \right)^{0.5} d^{2.5}$$

WEYMOUTH

FULLY TURBULENT FLOW

$$q_s = 18.062 \left(\frac{T_b}{P_b} \right) \left(\frac{P_1^2 - P_2^2}{L_m T_{avg} S_g} \right)^{0.5} d^{2.667}$$

PANHANDLE A

PARTIALLY TURBULENT FLOW

$$q_s = 18.161 \left[E \left(\frac{T_b}{P_b} \right) \right]^{1.0788} \left(\frac{P_1^2 - P_2^2}{L_m T_{avg} S_g^{0.8539}} \right)^{0.5394} d^{2.6182}$$

- ▶ A natural gas pipeline made of 14" schedule 20 pipe is 100 miles long.
The inlet pressure is 1300 psia, the outlet pressure is 300 psia, and the average temperature is 40°F. The gas consists of :
75% Methane (CH₄) + 21% Ethane (C₂H₆) + 4% Propane (C₃H₈)

Let's find the flow rate in millions of standard cubic feet per day (Mscfd)

14" Pipe internal diameter : 13.376 in

Friction factor (f) : 0.0128 **Complete turbulence**

MW Gas : 20.06 g/mol

S_g = 0.693

T_{avg} = 40°F = 277.59 °K

$$q_s = 3.2308 \left(\frac{T_b}{P_b} \right) \left(\frac{P_1^2 - P_2^2}{f L_m T_{avg} S_g} \right)^{0.5} d^{2.5}$$

➔ **107.9 Mscfd**

WEYMOUTH

FULLY TURBULENT FLOW

$$q_s = 18.062 \left(\frac{T_b}{P_b} \right) \left(\frac{P_1^2 - P_2^2}{L_m T_{avg} S_g} \right)^{0.5} d^{2.667}$$

➔ **105.2 Mscfd**

PANHANDLE A

PARTIALLY TURBULENT FLOW

$$q_s = 18.161 \left[E \left(\frac{T_b}{P_b} \right) \right]^{1.0788} \left(\frac{P_1^2 - P_2^2}{L_m T_{avg} S_g^{0.8539}} \right)^{0.5394} d^{2.6182}$$

➔ **128.4 Mscfd**

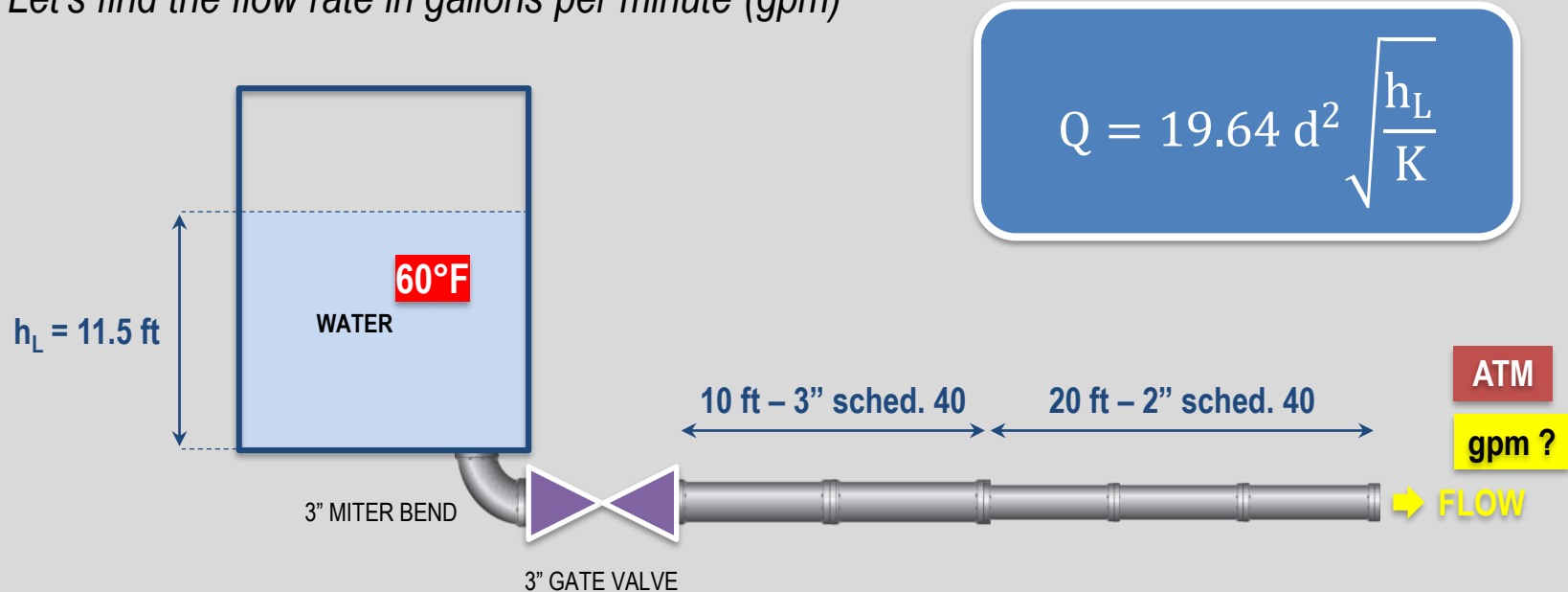
CONCRETE EXAMPLE # 15

FLOW THROUGH PIPES

WATER DISCHARGING FROM A RESERVOIR

- Water at 60°F is flowing from a reservoir through the piping system as depicted below. The reservoir has a constant head of 11.5 ft

Let's find the flow rate in gallons per minute (gpm)



$$Q = 19.64 d^2 \sqrt{\frac{h_L}{K}}$$

2" Pipe internal diameter : 2.067 in

3" Pipe internal diameter : 3.068 in

Water dynamic viscosity at 60°F (μ) : 1.1 cP

Water weight density at 60°F (ρ) : 62.364 lb/ft³

SYSTEM RESISTANCE :

Entrance (K_1) : 0.5

3" Mitre bend (K_2) : 1.08

Gate valve (K_3) : 0.144

Sudden contraction (K_4) : 1.32

10 ft 3" pipe (K_5) : 0.66

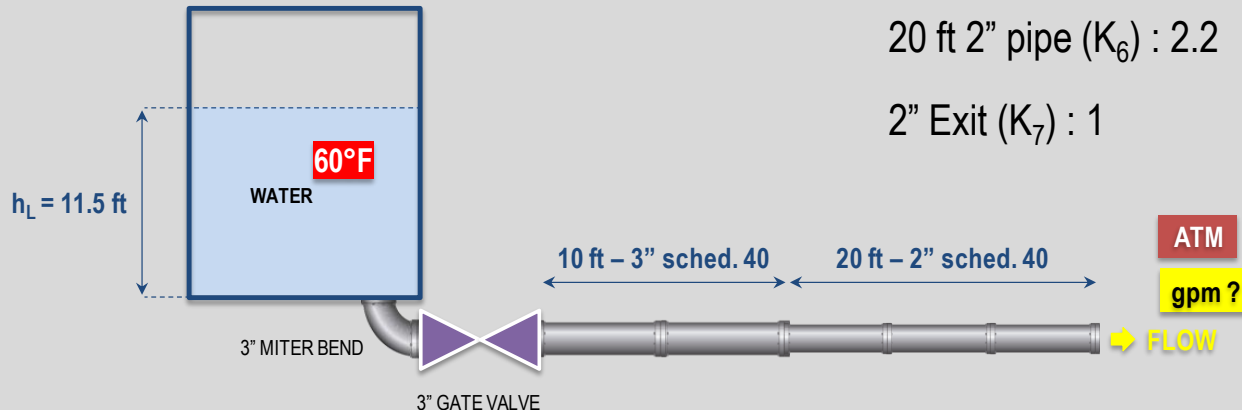
20 ft 2" pipe (K_6) : 2.2

2" Exit (K_7) : 1

$$K = f \frac{L}{D}$$

$$f_{3"} = 0.017$$

$$f_{2"} = 0.019$$



$$Q = 19.64 d^2 \sqrt{\frac{h_L}{K}}$$

2" Pipe internal diameter : 2.067 in

3" Pipe internal diameter : 3.068 in

Water dynamic viscosity at 60°F (μ) : 1.1 cP

Water weight density at 60°F (ρ) : 62.364 lb/ft³

SYSTEM RESISTANCE :

Entrance (K_1) : 0.5

3" Mitre bend (K_2) : 1.08

Gate valve (K_3) : 0.144

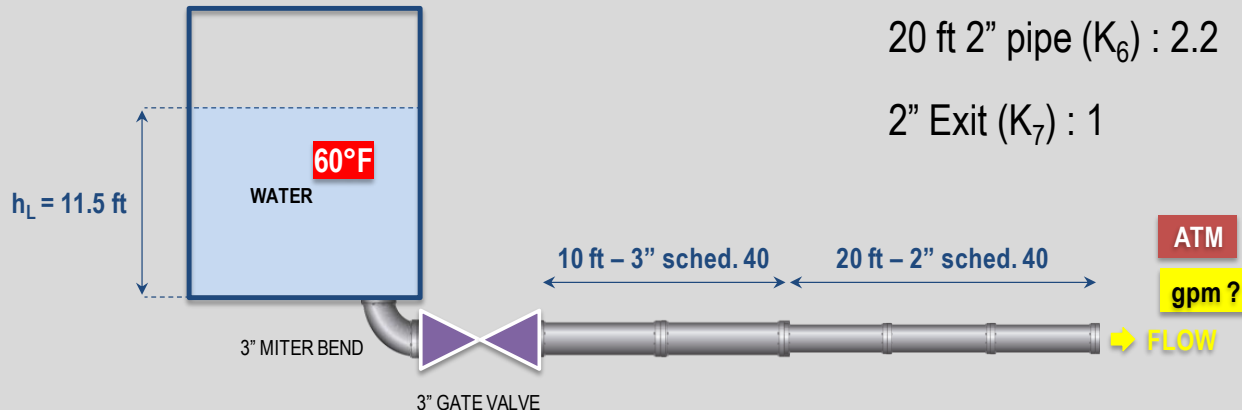
Sudden contraction (K_4) : 1.32

10 ft 3" pipe (K_5) : 0.66

20 ft 2" pipe (K_6) : 2.2

2" Exit (K_7) : 1

$$K_{2'' \gg 3''} = f_{2''} \frac{L_{2''}}{D_{2''} \beta^4}$$



$$Q = 19.64 d^2 \sqrt{\frac{h_L}{K}}$$

2" Pipe internal diameter : 2.067 in

3" Pipe internal diameter : 3.068 in

Water dynamic viscosity at 60°F (μ) : 1.1 cP

Water weight density at 60°F (ρ) : 62.364 lb/ft³

SYSTEM RESISTANCE :

Entrance (K_1) : 0.5

3" Mitre bend (K_2) : 1.08

Gate valve (K_3) : 0.144

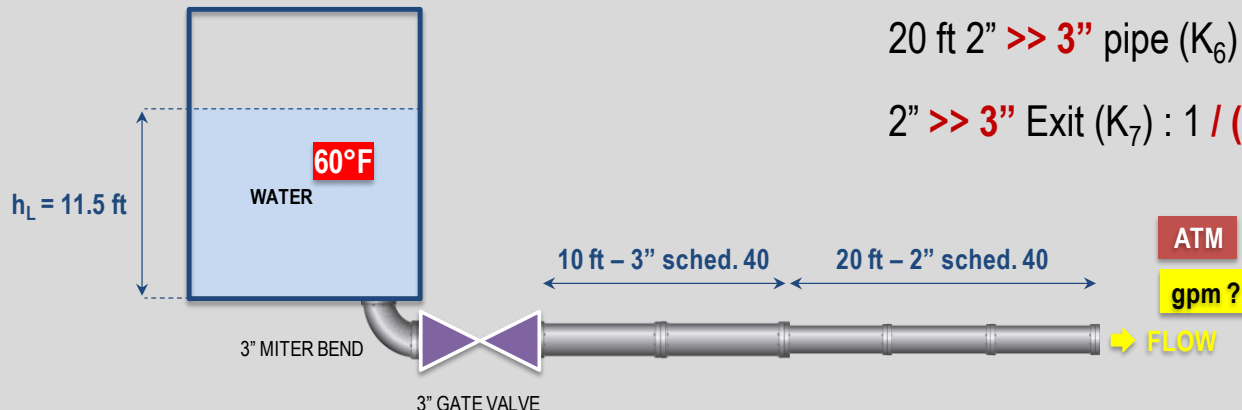
Sudden contraction (K_4) : 1.32

10 ft 3" pipe (K_5) : 0.66

20 ft 2" >> 3" pipe (K_6) : $2.2 / (2.067/3.068)^4$

2" >> 3" Exit (K_7) : $1 / (2.067/3.068)^4$

$$K_{2'' \gg 3''} = f_{2''} \frac{L_{2''}}{D_{2''} \beta^4}$$



$$Q = 19.64 d^2 \sqrt{\frac{h_L}{K}}$$

2" Pipe internal diameter : 2.067 in

3" Pipe internal diameter : 3.068 in

Water dynamic viscosity at 60°F (μ) : 1.1 cP

Water weight density at 60°F (ρ) : 62.364 lb/ft³

SYSTEM RESISTANCE :

Entrance (K_1) : 0.5

3" Mitre bend (K_2) : 1.08

Gate valve (K_3) : 0.144

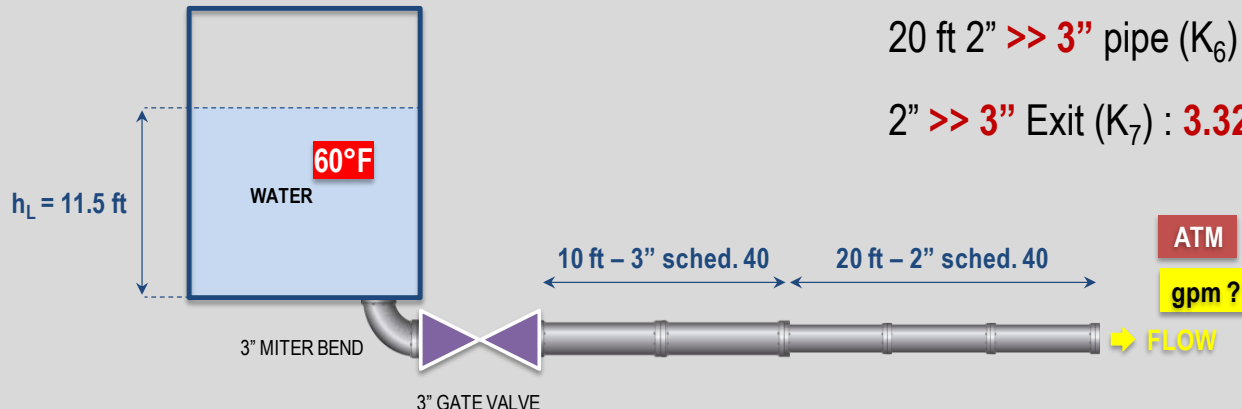
Sudden contraction (K_4) : 1.32

10 ft 3" pipe (K_5) : 0.66

20 ft 2" >> 3" pipe (K_6) : **10.9**

2" >> 3" Exit (K_7) : **3.32**

$$K_{2'' \gg 3''} = f_{2''} \frac{L_{2''}}{D_{2''} \beta^4}$$



$$Q = 19.64 d^2 \sqrt{\frac{h_L}{K}}$$

2" Pipe internal diameter : 2.067 in

3" Pipe internal diameter : 3.068 in

Water dynamic viscosity at 60°F (μ) : 1.1 cP

Water weight density at 60°F (ρ) : 62.364 lb/ft³

SYSTEM RESISTANCE :

Entrance (K_1) : 0.5

3" Mitre bend (K_2) : 1.08

Gate valve (K_3) : 0.144

Sudden contraction (K_4) : 1.32

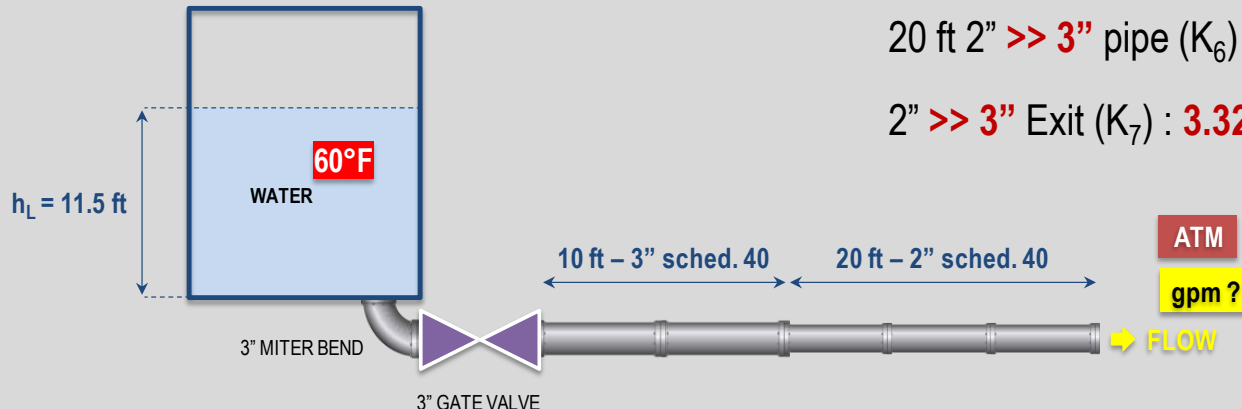
10 ft 3" pipe (K_5) : 0.66

20 ft 2" >> 3" pipe (K_6) : **10.9**

2" >> 3" Exit (K_7) : **3.32**

K_{total}

17.9



$$Q = 19.64 d^2 \sqrt{\frac{h_L}{K}}$$

2" Pipe internal diameter : 2.067 in

3" Pipe internal diameter : 3.068 in

Water dynamic viscosity at 60°F (μ) : 1.1 cP

Water weight density at 60°F (ρ) : 62.364 lb/ft³

SYSTEM RESISTANCE :

Entrance (K_1) : 0.5

3" Mitre bend (K_2) : 1.08

Gate valve (K_3) : 0.144

Sudden contraction (K_4) : 1.32

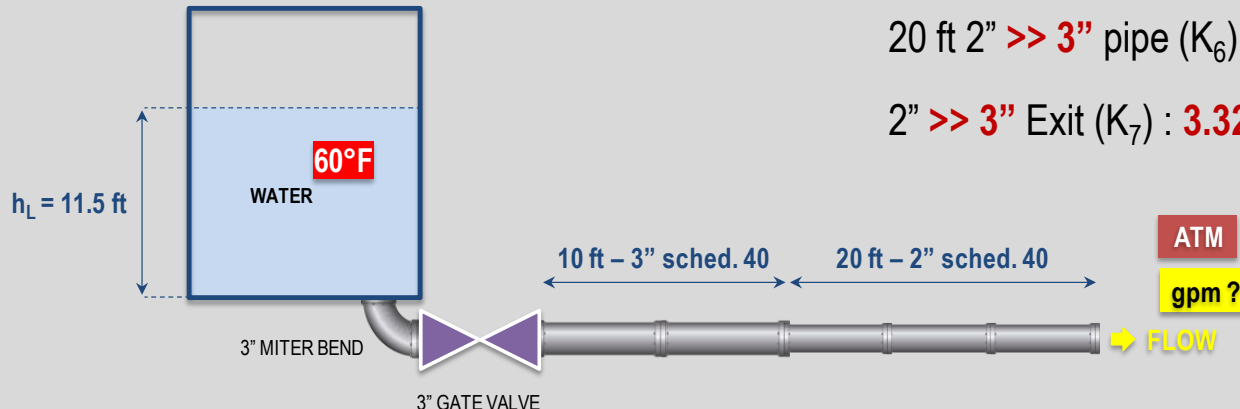
10 ft 3" pipe (K_5) : 0.66

20 ft 2" >> 3" pipe (K_6) : **10.9**

2" >> 3" Exit (K_7) : **3.32**

Q

148 gpm

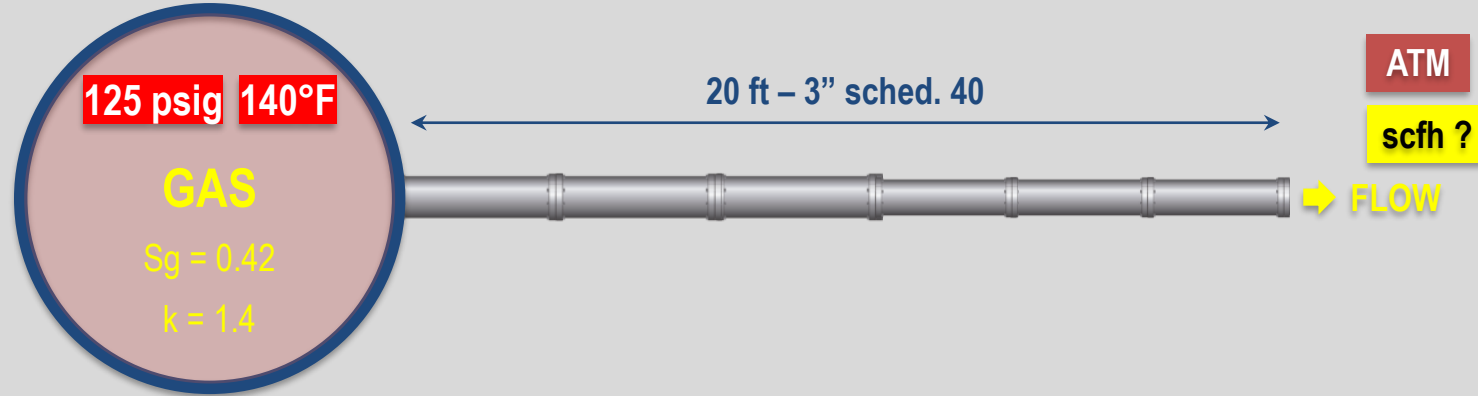


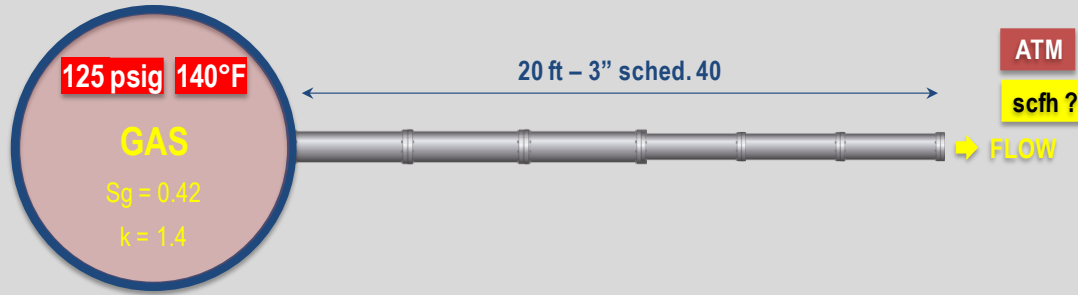
CONCRETE EXAMPLE # 16

FLOW THROUGH PIPES
GASES AT SONIC VELOCITY

- ▶ Coke oven gas having a specific gravity of 0.42, a header pressure of 125 psig, and a temperature of 140°F is flowing through 20 ft of 3" schedule 40 pipe before discharging to atmosphere. The ratio of specific heat is $k = 1.4$

Let's find the flow rate in standard cubic feet per hour





3" Pipe internal diameter : 3.068 in

Upstream pressure (psia) : 125 psig + 14.7

$$q_s = 40700 Y d^2 \sqrt{\frac{\Delta P \times P_{\text{upstream}}}{K T_{\text{upstream}} S_g}}$$

q_s : Standard rate of flow (scfh)

Y : Net expansibility factor (Unitless)

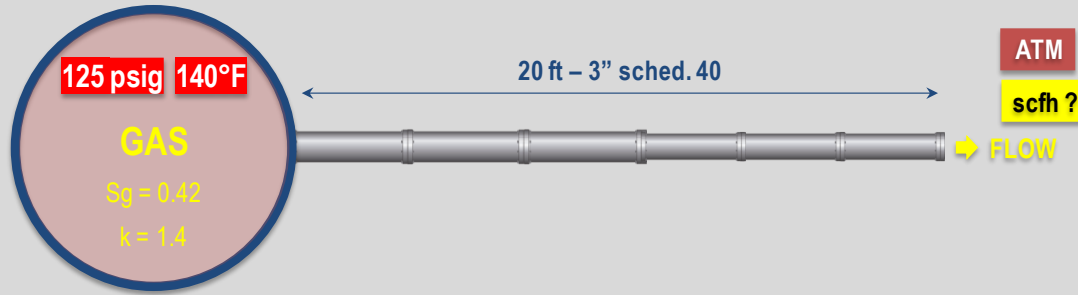
ΔP : Pressure differential (psi)

P_{upstream} : Absolute upstream pressure (psia)

K : Resistance coefficient (unitless)

T_{upstream} : Absolute upstream temperature (Kelvin)

S_g : Specific gravity of the gas relative to air (unitless)



3" Pipe internal diameter : 3.068 in

Upstream pressure (psia) : 139.7 psia

Pressure differential (ΔP) : 139.7 psia - ATM

$$q_s = 40700 Y d^2 \sqrt{\frac{\Delta P \times P_{\text{upstream}}}{K T_{\text{upstream}} S_g}}$$

q_s : Standard rate of flow (scfh)

Y : Net expansibility factor (Unitless)

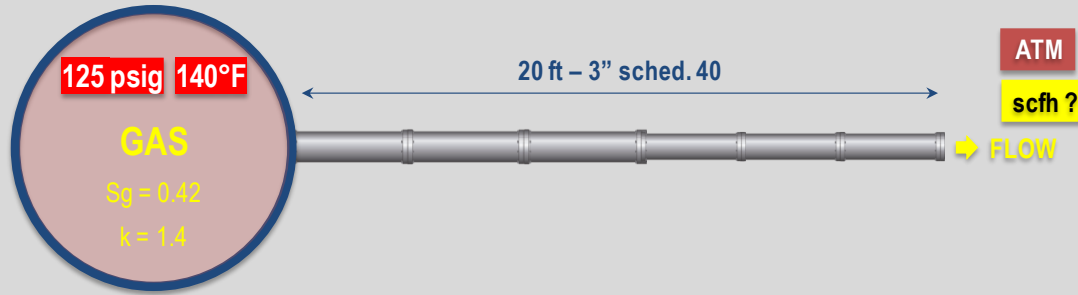
ΔP : Pressure differential (psi)

P_{upstream} : Absolute upstream pressure (psia)

K : Resistance coefficient (unitless)

T_{upstream} : Absolute upstream temperature (Kelvin)

S_g : Specific gravity of the gas relative to air (unitless)



3" Pipe internal diameter : 3.068 in

Upstream pressure (psia) : 139.7 psia

Pressure differential (ΔP) : 139.7 psia - 14.7 psia

$$q_s = 40700 Y d^2 \sqrt{\frac{\Delta P \times P_{\text{upstream}}}{K T_{\text{upstream}} S_g}}$$

q_s : Standard rate of flow (scfh)

Y : Net expansibility factor (Unitless)

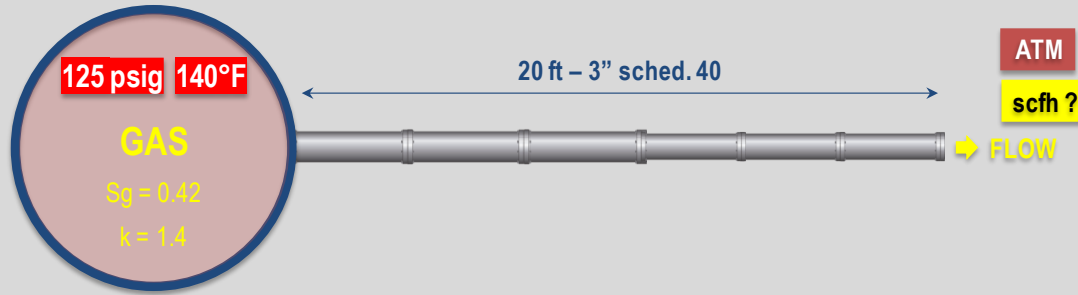
ΔP : Pressure differential (psi)

P_{upstream} : Absolute upstream pressure (psia)

K : Resistance coefficient (unitless)

T_{upstream} : Absolute upstream temperature (Kelvin)

S_g : Specific gravity of the gas relative to air (unitless)



3" Pipe internal diameter : 3.068 in

Upstream pressure (psia) : 139.7 psia

Pressure differential (ΔP) : 125 psi

Gas temperature (K) : 140°F = 333.15°K

$S_g = MW_{\text{gas}} / MW_{\text{air}} = MW_{\text{gas}} / 29 = 0.42$

Friction factor for 3" pipe (f) ~ 0.0175

$$q_s = 40700 Y d^2 \sqrt{\frac{\Delta P \times P_{\text{upstream}}}{K T_{\text{upstream}} S_g}}$$

q_s : Standard rate of flow (scfh)

Y : Net expansibility factor (Unitless)

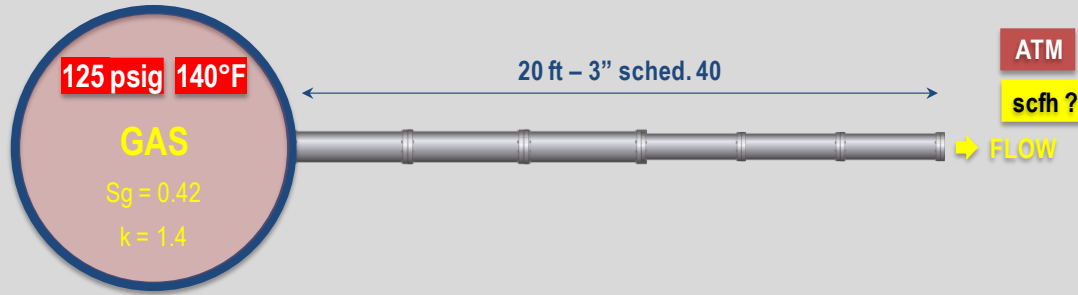
ΔP : Pressure differential (psi)

P_{upstream} : Absolute upstream pressure (psia)

K : Resistance coefficient (unitless)

T_{upstream} : Absolute upstream temperature (Kelvin)

S_g : Specific gravity of the gas relative to air (unitless)



$$q_s = 40700 Y d^2 \sqrt{\frac{\Delta P \times P_{\text{upstream}}}{K T_{\text{upstream}} S_g}}$$

3" Pipe internal diameter : 3.068 in

Upstream pressure (psia) : 139.7 psia

Pressure differential (ΔP) : 125 psi

Gas temperature (K) : 140°F = 333.15°K

$S_g = MW_{\text{gas}} / MW_{\text{air}} = MW_{\text{gas}} / 29 = 0.42$

Friction factor for 3" pipe (f) ~ 0.0175

SYSTEM RESISTANCE :

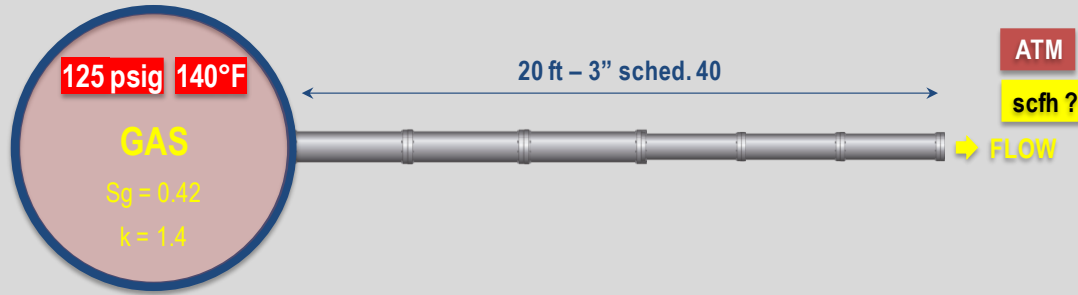
Entrance (K_1) : 0.5

20 ft 3" pipe (K_2) : 1.37

Exit (K_3) : 1

$$K = f \frac{L}{D}$$

$$K_{\text{total}} = 0.5 + 1.37 + 1$$



$$q_s = 40700 Y d^2 \sqrt{\frac{\Delta P \times P_{\text{upstream}}}{K T_{\text{upstream}} S_g}}$$

3" Pipe internal diameter : 3.068 in

Upstream pressure (psia) : 139.7 psia

Pressure differential (ΔP) : 125 psi

Gas temperature (K) : 140°F = 333.15°K

$S_g = MW_{\text{gas}} / MW_{\text{air}} = MW_{\text{gas}} / 29 = 0.42$

Friction factor for 3" pipe (f) ~ 0.0175

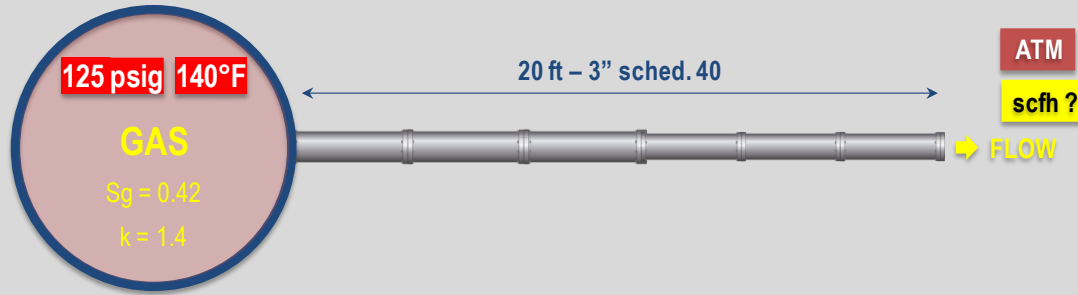
SYSTEM RESISTANCE :

Entrance (K_1) : 0.5

20 ft 3" pipe (K_2) : 1.37

Exit (K_3) : 1

$K_{\text{total}} = 2.87$



3" Pipe internal diameter : 3.068 in

Upstream pressure (psia) : 139.7 psia

Pressure differential (ΔP) : 125 psi

Gas temperature (K) : 140°F = 333.15°K

$S_g = MW_{\text{gas}} / MW_{\text{air}} = MW_{\text{gas}} / 29 = 0.42$

Friction factor for 3" pipe (f) ~ 0.0175

$K_{\text{total}} = 2.87$

$Y = 0.637$

$$q_s = 40700 Y d^2 \sqrt{\frac{\Delta P \times P_{\text{upstream}}}{K T_{\text{upstream}} S_g}}$$

q_s : Standard rate of flow (scfh)

Y : Net expansibility factor (Unitless)

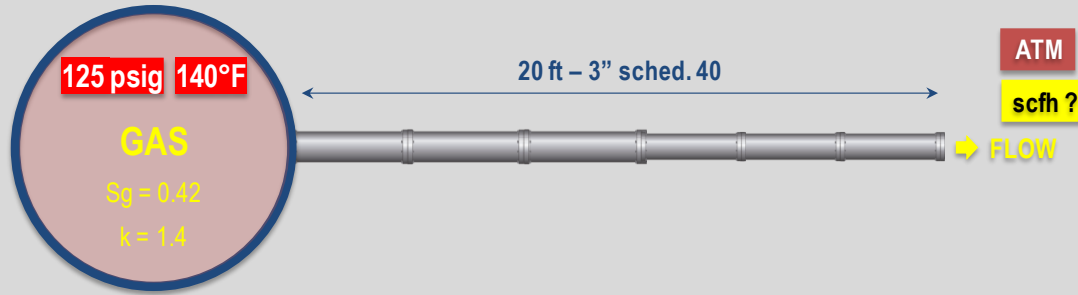
ΔP : Pressure differential (psi)

P_{upstream} : Absolute upstream pressure (psia)

K : Resistance coefficient (unitless)

T_{upstream} : Absolute upstream temperature (Kelvin)

S_g : Specific gravity of the gas relative to air (unitless)



$$q_s = 40700 Y d^2 \sqrt{\frac{\Delta P \times P_{\text{upstream}}}{K T_{\text{upstream}} S_g}}$$

3" Pipe internal diameter : 3.068 in

Upstream pressure (psia) : 139.7 psia

Pressure differential (ΔP) : 125 psi

Gas temperature (K) : 140°F = 333.15°K

$S_g = MW_{\text{gas}} / MW_{\text{air}} = MW_{\text{gas}} / 29 = 0.42$

Friction factor for 3" pipe (f) ~ 0.0175

$K_{\text{total}} = 2.87$

$Y = 0.637$

q_s

~1 Mscfh

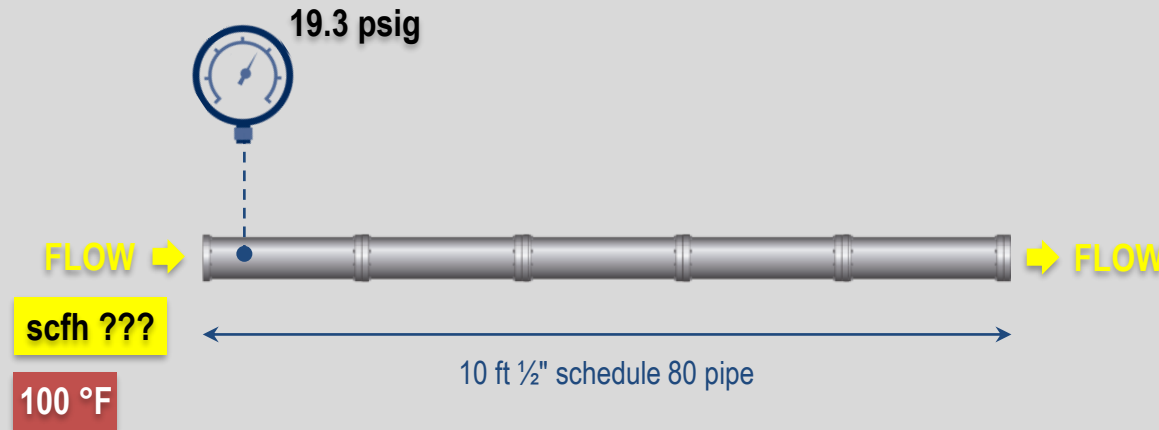
CONCRETE EXAMPLE # 17

FLOW THROUGH PIPES

COMPRESSIBLE FLUID AT SUBSONIC VELOCITY

- ▶ Air at a pressure of 19.3 psig and a temperature of 100°F is measured at a point 10 ft from the outlet of a ½" schedule 80 pipe discharging to atmosphere

Let's find the flow rate in standard cubic feet per hour



$$q_s = 40700 Y d^2 \sqrt{\frac{\Delta P \times P_{\text{upstream}}}{K T_{\text{upstream}} S_g}}$$

q_s : Standard rate of flow (scfh)

Y : Net expansibility factor (Unitless)

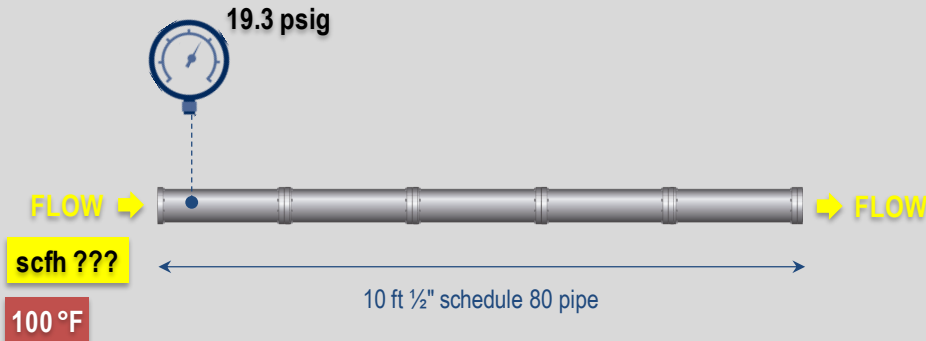
ΔP : Pressure differential (psi)

P_{upstream} : Absolute upstream pressure (psia)

K : Resistance coefficient (unitless)

T_{upstream} : Absolute upstream temperature (Kelvin)

S_g : Specific gravity of the gas relative to air (unitless)



1/2" Pipe internal diameter : 0.546 in

Upstream pressure (psia) : 34 psia (= 19.3 + 14.7)

Pressure differential (ΔP) : 19.3 psi

Gas temperature (K) : 100°F = 310.93°K

$S_g = MW_{\text{air}} / MW_{\text{air}} = 1$

Friction factor for 1/2" pipe (f) ~ 0.0275

SYSTEM RESISTANCE :

10 ft 1/2" pipe (K_1) : 6.04

Exit (K_2) : 1

$K_{\text{total}} = 7.04$

$$K = f \frac{L}{D}$$

$$q_s = 40700 Y d^2 \sqrt{\frac{\Delta P \times P_{\text{upstream}}}{K T_{\text{upstream}} S_g}}$$

q_s : Standard rate of flow (scfh)

Y : Net expansibility factor (Unitless)

ΔP : Pressure differential (psi)

P_{upstream} : Absolute upstream pressure (psia)

K : Resistance coefficient (unitless)

T_{upstream} : Absolute upstream temperature (Kelvin)

S_g : Specific gravity of the gas relative to air (unitless)

½" Pipe internal diameter : 0.546 in

Upstream pressure (psia) : 34 psia (= 19.3 + 14.7)

Pressure differential (ΔP) : 19.3 psi

Gas temperature (K) : 100°F = 310.93°K

$S_g = MW_{\text{air}} / MW_{\text{air}} = 1$

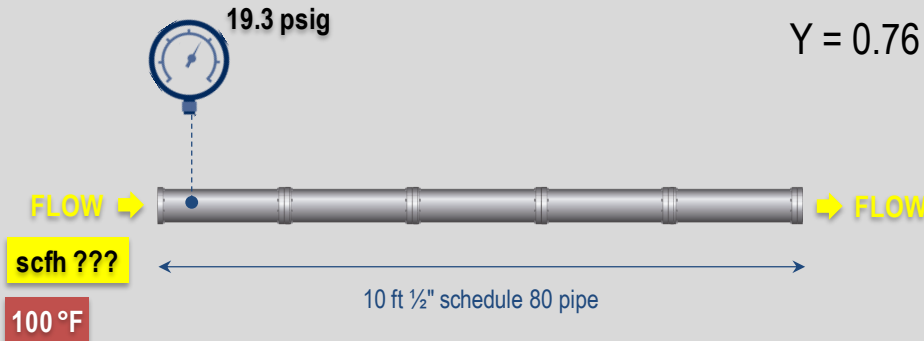
Friction factor for ½" pipe (f) ~ 0.0275

$K = 7.04$

$Y = 0.76$

q_s

3762 scfh



CONCRETE EXAMPLE # 18

FLOW THROUGH ORIFICE METERS

LIQUID FLOW IN FULLY TURBULENT FLOW

- ▶ A square edge orifice of 2" diameter is installed in a 4" schedule 40 pipe having a mercury manometer connected between taps located 1D upstream and ½D downstream

Let's find the theoretical calibration constant for the meter when used on 60°F water and for the flow range where the orifice flow coefficient C is constant

$$\Delta P = \frac{\rho \Delta h}{144}$$

ΔP : Pressure drop (psi)

Δh : Head loss (ft)

ρ : Weight density of Hg (lb/ft³)

- ▶ A square edge orifice of 2" diameter is installed in a 4" schedule 40 pipe having a mercury manometer connected between taps located 1D upstream and ½D downstream

Let's find the theoretical calibration constant for the meter when used on 60°F water and for the flow range where the orifice flow coefficient C is constant

4" Pipe internal diameter : 4.026 in

Water weight density at 60°F (ρ) : 62.364 lb/ft³

Mercury weight density at 60°F (ρ) :

S_w : 1

S_{Hg} : 13.57

$$\rho_{Hg} = \rho_w (S_{Hg} - S_w)$$

$$\Delta P = \frac{\rho \Delta h_{\text{mercury}}}{12 \times 144}$$

ΔP : Pressure drop (psi)

Δh : Head loss (inches of Hg)

ρ : Weight density of Hg (lb/ft³)

- ▶ A square edge orifice of 2" diameter is installed in a 4" schedule 40 pipe having a mercury manometer connected between taps located 1D upstream and ½D downstream

Let's find the theoretical calibration constant for the meter when used on 60°F water and for the flow range where the orifice flow coefficient C is constant

4" Pipe internal diameter : 4.026 in

Water weight density at 60°F (ρ) : 62.364 lb/ft³

Mercury weight density at 60°F (ρ) :

S_w : 1

S_{Hg} : 13.57

$$\rho_{Hg} = 62.364 \times (13.57 - 1)$$

$$\Delta P = \frac{\rho \Delta h_{\text{mercury}}}{12 \times 144}$$

ΔP : Pressure drop (psi)

Δh : Head loss (inches of Hg)

ρ : Weight density of Hg (lb/ft³)

- ▶ A square edge orifice of 2" diameter is installed in a 4" schedule 40 pipe having a mercury manometer connected between taps located 1D upstream and ½D downstream

Let's find the theoretical calibration constant for the meter when used on 60°F water and for the flow range where the orifice flow coefficient C is constant

4" Pipe internal diameter : 4.026 in

Water weight density at 60°F (ρ) : 62.364 lb/ft³

Mercury weight density at 60°F (ρ) : 784 lb/ft³

S_w : 1

S_{Hg} : 13.57

$$\rho_{Hg} = 784 \text{ lb/ft}^3$$

$$\Delta P = \frac{\rho \Delta h_{\text{mercury}}}{12 \times 144}$$

ΔP : Pressure drop (psi)

Δh : Head loss (inches of Hg)

ρ : Weight density of Hg (lb/ft³)

- ▶ A square edge orifice of 2" diameter is installed in a 4" schedule 40 pipe having a mercury manometer connected between taps located 1D upstream and ½D downstream

Let's find the theoretical calibration constant for the meter when used on 60°F water and for the flow range where the orifice flow coefficient C is constant

4" Pipe internal diameter : 4.026 in

Water weight density at 60°F (ρ) : 62.364 lb/ft³

Mercury weight density at 60°F (ρ) : 784 lb/ft³

$$\Delta P = 784 \frac{\Delta h_{\text{mercury}}}{12 \times 144}$$

ΔP : Pressure drop (psi)

Δh : Head loss (inches of Hg)

- ▶ A square edge orifice of 2" diameter is installed in a 4" schedule 40 pipe having a mercury manometer connected between taps located 1D upstream and ½D downstream

Let's find the theoretical calibration constant for the meter when used on 60°F water and for the flow range where the orifice flow coefficient C is constant

4" Pipe internal diameter : 4.026 in

Water weight density at 60°F (ρ) : 62.364 lb/ft³

Mercury weight density at 60°F (ρ) : 784 lb/ft³

$$\Delta P = 0.454 \Delta h_{\text{mercury}}$$

ΔP : Pressure drop (psi)

Δh : Head loss (inches of Hg)

- ▶ A square edge orifice of 2" diameter is installed in a 4" schedule 40 pipe having a mercury manometer connected between taps located 1D upstream and ½D downstream

Let's find the theoretical calibration constant for the meter when used on 60°F water and for the flow range where the orifice flow coefficient C is constant

4" Pipe internal diameter : 4.026 in

Water weight density at 60°F (ρ) : 62.364 lb/ft³

Mercury weight density at 60°F (ρ) : 784 lb/ft³

$$\Delta P = 0.454 \Delta h_{\text{mercury}}$$

$$Q = 235.6 d_{\text{orifice}}^2 C \sqrt{\frac{\Delta P}{\rho}}$$

Q : Rate of flow (gpm)

ΔP : Pressure drop (psi)

C : Flow coefficient (unitless)

Δh : Head loss (inches of Hg)

ρ : Weight density of water (lb/ft³)

- ▶ A square edge orifice of 2" diameter is installed in a 4" schedule 40 pipe having a mercury manometer connected between taps located 1D upstream and ½D downstream

Let's find the theoretical calibration constant for the meter when used on 60°F water and for the flow range where the orifice flow coefficient C is constant

4" Pipe internal diameter : 4.026 in

Water weight density at 60°F (ρ) : 62.364 lb/ft³

Mercury weight density at 60°F (ρ) : 784 lb/ft³

$$d_{\text{orifice}} / d_{\text{pipe}} = 0.497$$

$C = 0.625 \rightarrow$ assuming a **fully turbulent flow**

$$Q = 158.7 d_{\text{orifice}}^2 C \sqrt{\frac{\Delta h_{\text{mercury}}}{\rho}}$$

Q : Rate of flow (gpm)

ΔP : Pressure drop (psi)

C : Flow coefficient (unitless)

Δh : Head loss (**inches of Hg**)

ρ : Weight density of water (lb/ft³)

- ▶ A square edge orifice of 2" diameter is installed in a 4" schedule 40 pipe having a mercury manometer connected between taps located 1D upstream and ½D downstream

Let's find the theoretical calibration constant for the meter when used on 60°F water and for the flow range where the orifice flow coefficient C is constant

4" Pipe internal diameter : 4.026 in

Water weight density at 60°F (ρ) : 62.364 lb/ft³

Mercury weight density at 60°F (ρ) : 784 lb/ft³

$d_{\text{orifice}} / d_{\text{pipe}} = 0.497$

$C = 0.625 \rightarrow$ assuming a **fully turbulent flow**

$$Q = 158.7 \times 2^2 \times 0.625 \sqrt{\frac{\Delta h_{\text{mercury}}}{62.364}}$$

Q : Rate of flow (gpm)

ΔP : Pressure drop (psi)

C : Flow coefficient (unitless)

Δh : Head loss (**inches of Hg**)

ρ : Weight density of water (lb/ft³)

- ▶ A square edge orifice of 2" diameter is installed in a 4" schedule 40 pipe having a mercury manometer connected between taps located 1D upstream and ½D downstream

Let's find the theoretical calibration constant for the meter when used on 60°F water and for the flow range where the orifice flow coefficient C is constant

4" Pipe internal diameter : 4.026 in

Water weight density at 60°F (ρ) : 62.364 lb/ft³

Mercury weight density at 60°F (ρ) : 784 lb/ft³

$d_{\text{orifice}} / d_{\text{pipe}} = 0.497$

$C = 0.625 \rightarrow$ assuming a **fully turbulent flow**

$$Q = 50.3 \sqrt{\Delta h_{\text{mercury}}}$$

Q : Rate of flow (gpm)

ΔP : Pressure drop (psi)

C : Flow coefficient (unitless)

Δh : Head loss (**inches of Hg**)

ρ : Weight density of water (lb/ft³)

- ▶ A square edge orifice of 2" diameter is installed in a 4" schedule 40 pipe having a mercury manometer connected between taps located 1D upstream and ½D downstream

→ *Let's now calculate the flow rate of 60°F water when the mercury deflection is 4.4"*

4" Pipe internal diameter : 4.026 in

Water weight density at 60°F (ρ) : 62.364 lb/ft³

Mercury weight density at 60°F (ρ) : 784 lb/ft³

$d_{\text{orifice}} / d_{\text{pipe}} = 0.497$

$C = 0.625$ → assuming a **fully turbulent flow**

$$Q = 50.3 \sqrt{\Delta h_{\text{mercury}}}$$

Q : Rate of flow (gpm)

ΔP : Pressure drop (psi)

C : Flow coefficient (unitless)

Δh : Head loss (**inches of Hg**)

ρ : Weight density of water (lb/ft³)

- ▶ A square edge orifice of 2" diameter is installed in a 4" schedule 40 pipe having a mercury manometer connected between taps located 1D upstream and ½D downstream

→ *Let's now calculate the flow rate of 60°F water when the mercury deflection is 4.4"*

4" Pipe internal diameter : 4.026 in

Water weight density at 60°F (ρ) : 62.364 lb/ft³

Mercury weight density at 60°F (ρ) : 784 lb/ft³

$d_{\text{orifice}} / d_{\text{pipe}} = 0.497$

$C = 0.625$ → assuming a **fully turbulent flow**

$$Q = 50.3\sqrt{4.4}$$

Q : Rate of flow (gpm)

ΔP : Pressure drop (psi)

C : Flow coefficient (unitless)

Δh : Head loss (**inches of Hg**)

ρ : Weight density of water (lb/ft³)

- ▶ A square edge orifice of 2" diameter is installed in a 4" schedule 40 pipe having a mercury manometer connected between taps located 1D upstream and ½D downstream

→ *Let's now calculate the flow rate of 60°F water when the mercury deflection is 4.4"*

4" Pipe internal diameter : 4.026 in

Water weight density at 60°F (ρ) : 62.364 lb/ft³

Mercury weight density at 60°F (ρ) : 784 lb/ft³

$$d_{\text{orifice}} / d_{\text{pipe}} = 0.497$$

C = 0.625 → assuming a **fully turbulent flow**

$$Q = 106 \text{ gpm}$$

Q : Rate of flow (gpm)

ΔP : Pressure drop (psi)

C : Flow coefficient (unitless)

Δh : Head loss (**inches of Hg**)

ρ : Weight density of water (lb/ft³)

CONCRETE EXAMPLE # 19

FLOW THROUGH ORIFICE METERS
LIQUID FLOW IN LAMINAR FLOW

- ▶ S.A.E 10W Oil is flowing through a 3" schedule 40 pipe and produces 0.4 psi pressure differential between the pipe taps of a 2.15" ID square edged orifice

Let's find the flow rate in gallons per minute (gpm). (Weight density of oil = 53.6 lb/ft³)

3" Pipe internal diameter : 3.068 in

$$d_{\text{orifice}} / d_{\text{pipe}} = 0.497$$

C = 0.75 → assuming a **laminar** flow

$$Q = 235.6 d_{\text{orifice}}^2 C \sqrt{\frac{\Delta P}{\rho}}$$

Q : Rate of flow (gpm)

C : Flow coefficient (unitless)

ρ : Weight density of water (lb/ft³)

ΔP : Pressure drop (psi)

- ▶ S.A.E 10W Oil is flowing through a 3" schedule 40 pipe and produces 0.4 psi pressure differential between the pipe taps of a 2.15" ID square edged orifice

Let's find the flow rate in gallons per minute (gpm). (Weight density of oil = 53.6 lb/ft³)

3" Pipe internal diameter : 3.068 in

$$d_{\text{orifice}} / d_{\text{pipe}} = 0.497$$

C = 0.75 → assuming a **laminar flow** with a corresponding Reynolds number : 5000

$$Q = 235.6 d_{\text{orifice}}^2 C \sqrt{\frac{\Delta P}{\rho}}$$

Q

~70 gpm

Q : Rate of flow (gpm)

C : Flow coefficient (unitless)

ρ : Weight density of water (lb/ft³)

ΔP : Pressure drop (psi)

- ▶ S.A.E 10W Oil is flowing through a 3" schedule 40 pipe and produces 0.4 psi pressure differential between the pipe taps of a 2.15" ID square edged orifice

Let's find the flow rate in gallons per minute (gpm). (Weight density of oil = 53.6 lb/ft³)

3" Pipe internal diameter : 3.068 in

$$d_{\text{orifice}} / d_{\text{pipe}} = 0.497$$

C = 0.75 → assuming a **laminar flow** with a corresponding Reynolds number : 5000

Q

~70 gpm

$$Re = 50.66 \frac{\rho Q}{d \mu}$$

Q : Rate of flow (gpm)

d : Pipe internal diameter (in)

ρ : Weight density of water (lb/ft³)

μ : Dynamic viscosity (cP)

- ▶ S.A.E 10W Oil is flowing through a 3" schedule 40 pipe and produces 0.4 psi pressure differential between the pipe taps of a 2.15" ID square edged orifice

Let's find the flow rate in gallons per minute (gpm). (Weight density of oil = 53.6 lb/ft³)

3" Pipe internal diameter : 3.068 in

$$d_{\text{orifice}} / d_{\text{pipe}} = 0.497$$

C = 0.75 → assuming a **laminar flow** with a corresponding Reynolds number : 5000

$$Re = 1562$$

Q

~70 gpm

Q : Rate of flow (gpm)

d : Pipe internal diameter (in)

ρ : Weight density of water (lb/ft³)

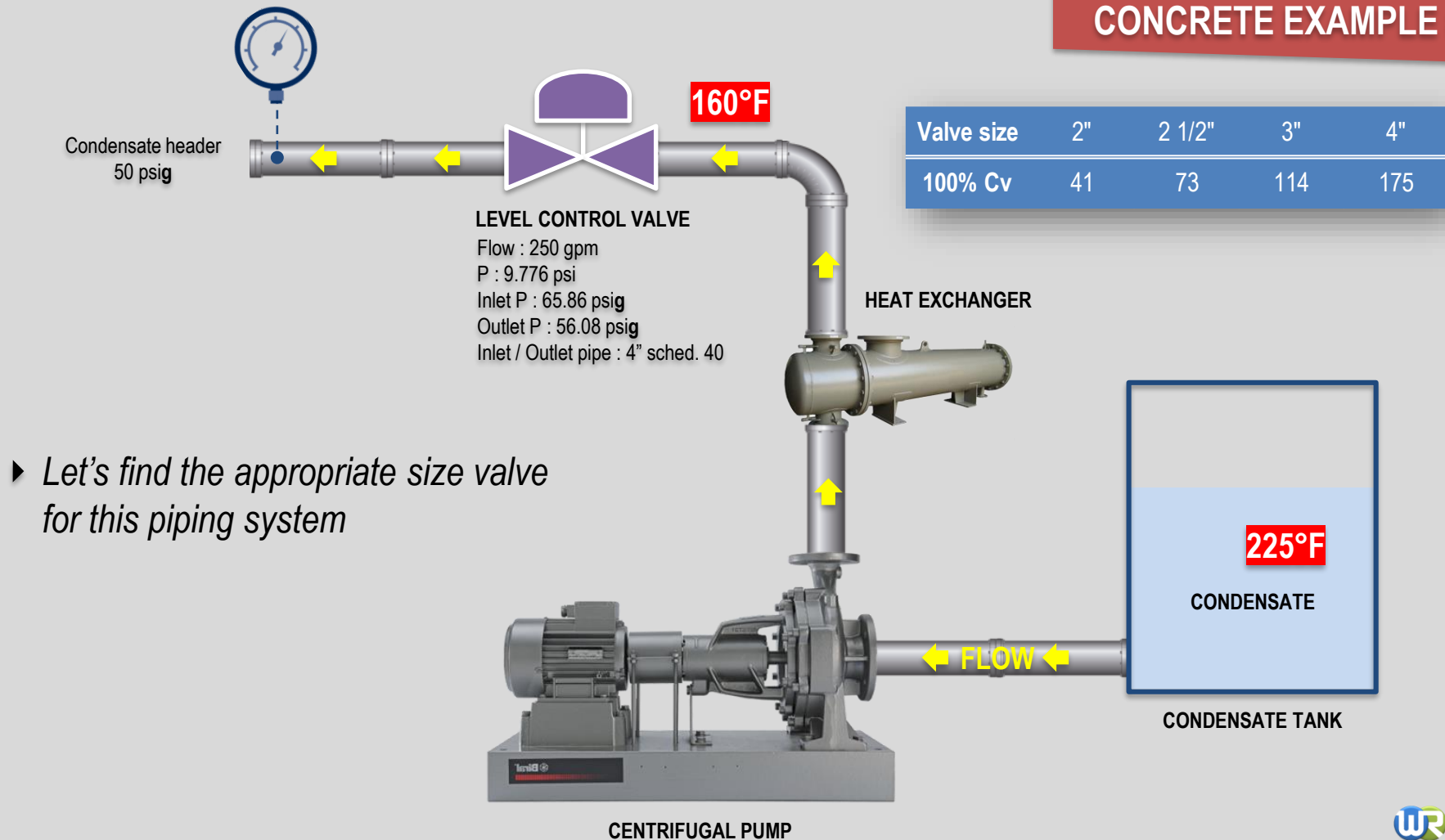
μ : Dynamic viscosity (cP)

CONCRETE EXAMPLE # 20

CONTROL VALVES

SIZING CONTROL VALVES
FOR LIQUID SERVICE

CONCRETE EXAMPLE #20



- *Let's find the appropriate size valve for this piping system*

Water weight density at 160°F (ρ) : 60.998 lb/ft³

Water dynamic viscosity at 160°F (μ) : 0.39 cP

Water vapor pressure at 160°F (P_s) : 4.75 psia

$$C_v = \frac{Q}{F_p \sqrt{\frac{\Delta P}{S}}}$$

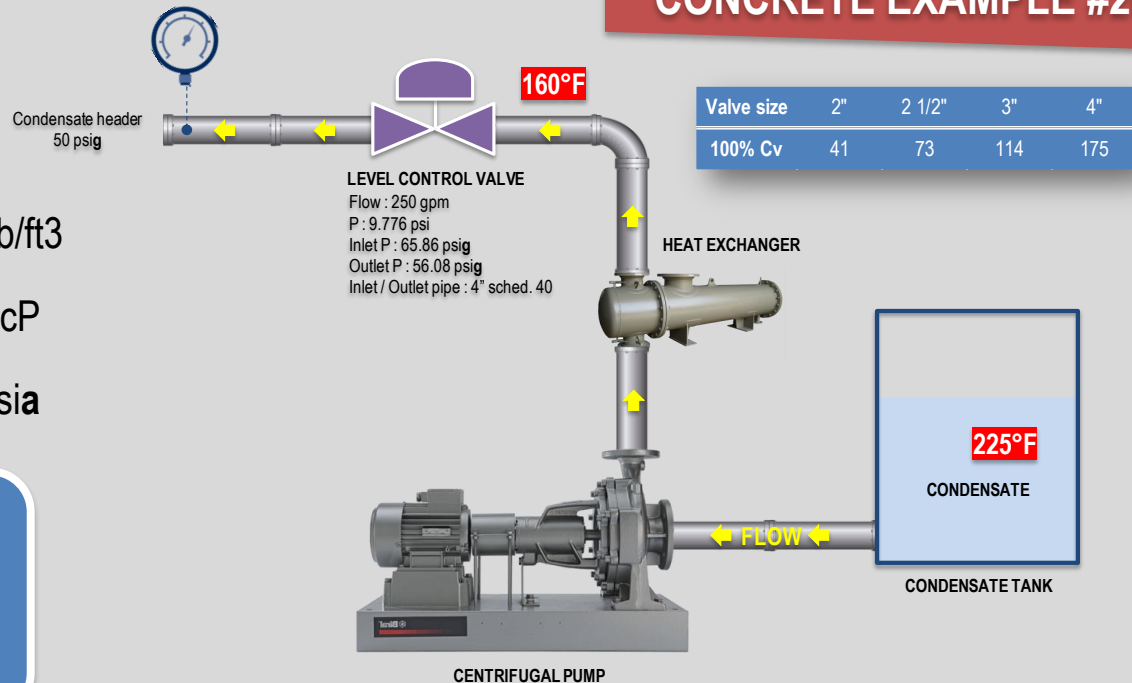
C_v : Valve flow coefficient

ΔP : Pressure differential (psi)

Q : Rate of flow (gpm)

S : Specific gravity of liquids

F_p : Piping geometry factor (unitless)



- *Let's find the appropriate size valve for this piping system*

Water weight density at 160°F (ρ) : 60.998 lb/ft³

Water dynamic viscosity at 160°F (μ) : 0.39 cP

Water vapor pressure at 160°F (P_s) : 4.75 psia

$$C_v = \frac{250}{1 \sqrt{\frac{80.6 - 70.8}{\frac{60.998}{62.364}}}}$$

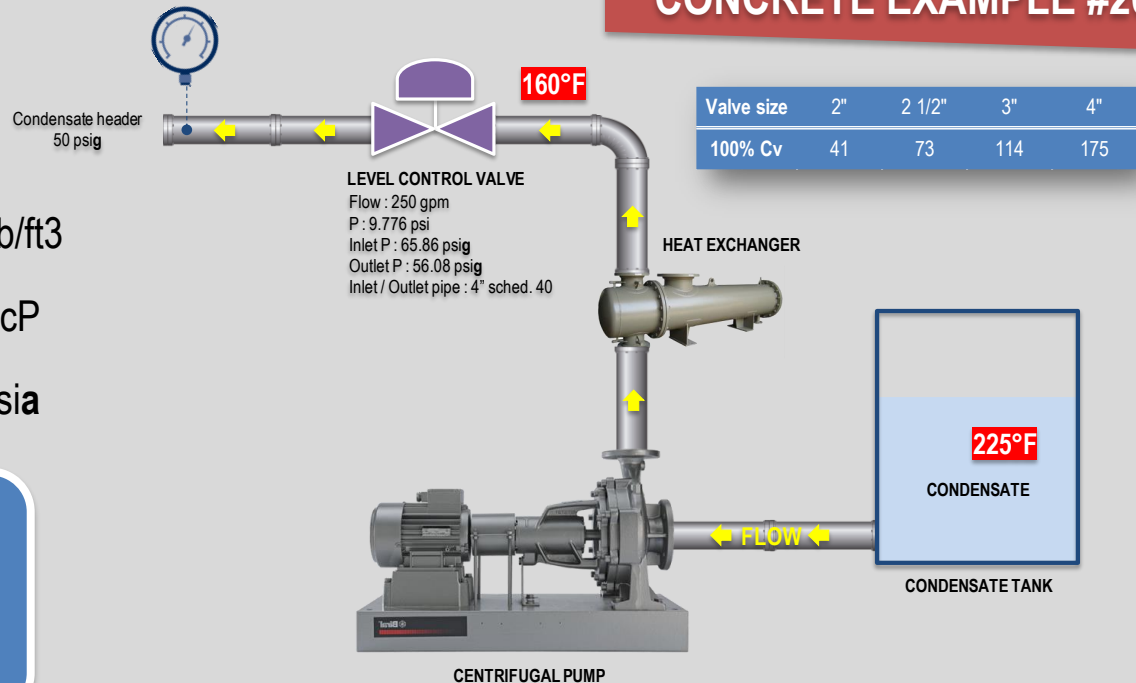
C_v : Valve flow coefficient

Q : Rate of flow (gpm)

F_p : Piping geometry factor (unitless)

ΔP : Pressure differential (psi)

S : Specific gravity of liquids



- *Let's find the appropriate size valve for this piping system*

Water weight density at 160°F (ρ) : 60.998 lb/ft³

Water dynamic viscosity at 160°F (μ) : 0.39 cP

Water vapor pressure at 160°F (P_s) : 4.75 psia

$$C_v = 78.98$$

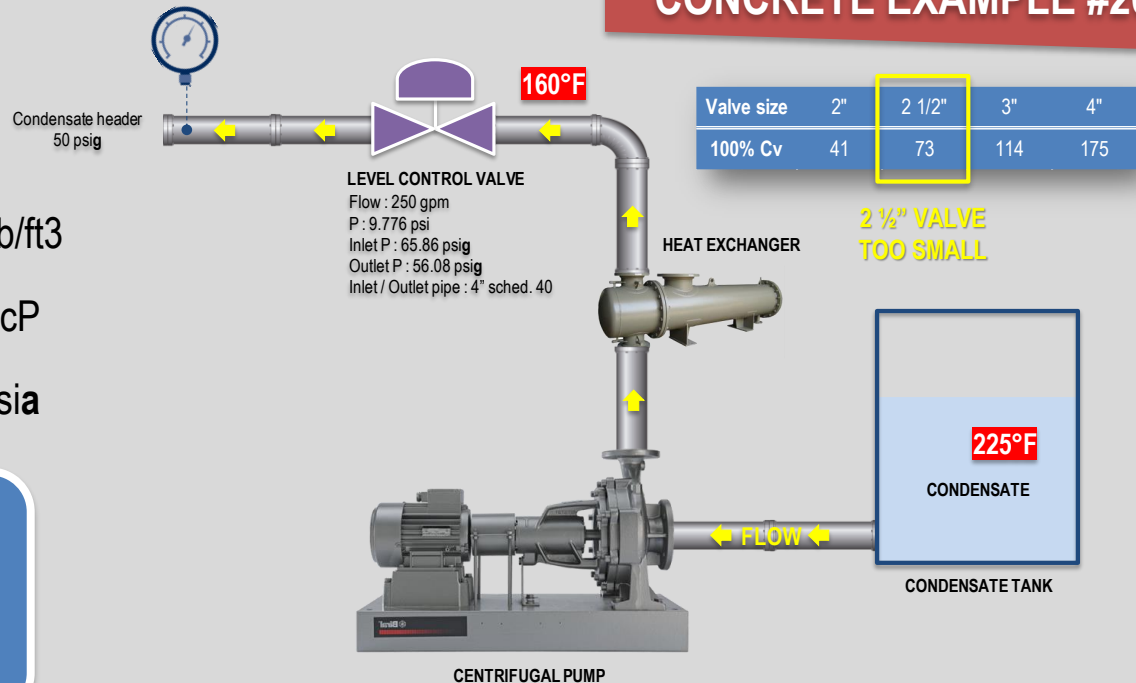
C_v : Valve flow coefficient

Q : Rate of flow (gpm)

F_p : Piping geometry factor (unitless)

ΔP : Pressure differential (psi)

S : Specific gravity of liquids



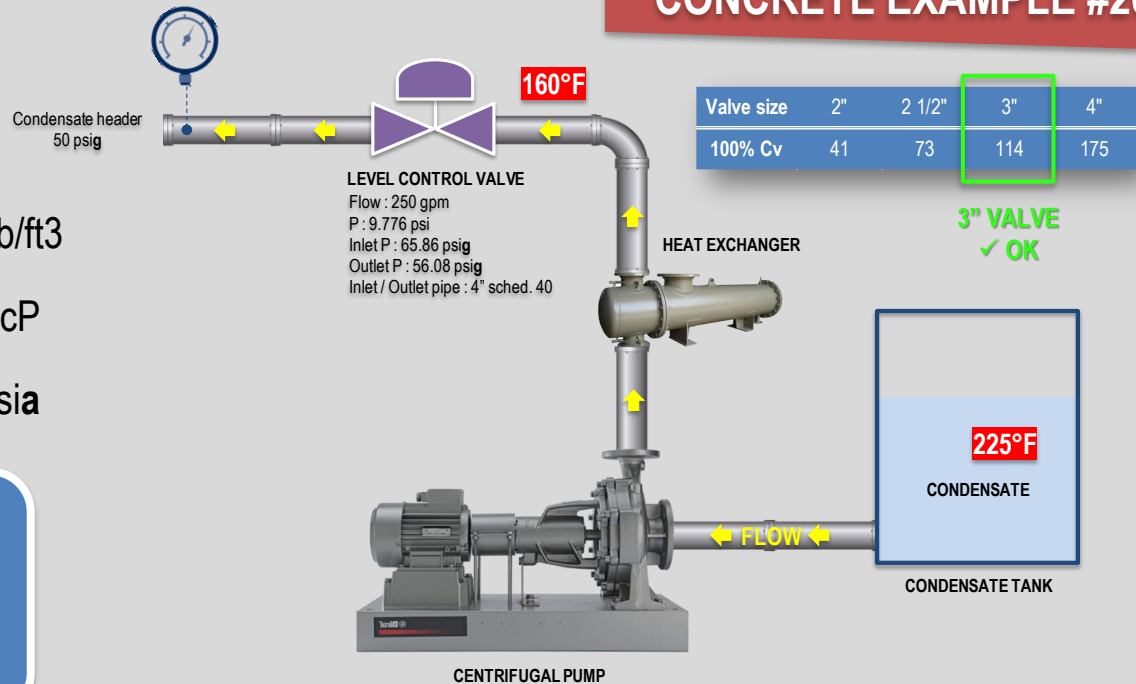
- *Let's find the appropriate size valve for this piping system*

Water weight density at 160°F (ρ) : 60.998 lb/ft³

Water dynamic viscosity at 160°F (μ) : 0.39 cP

Water vapor pressure at 160°F (P_s) : 4.75 psia

$$C_v = 78.98$$



C_v : Valve flow coefficient

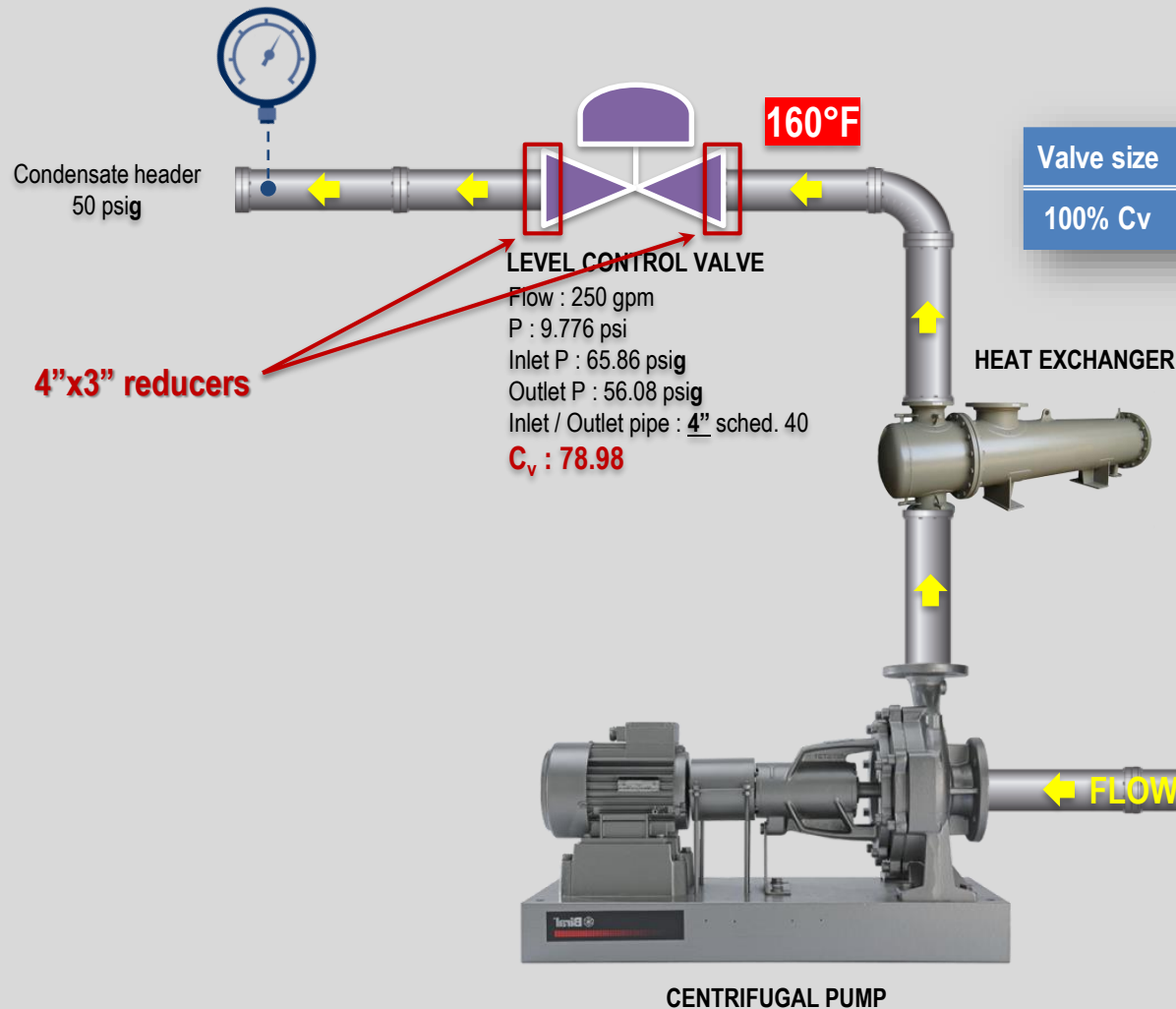
ΔP : Pressure differential (psi)

Q : Rate of flow (gpm)

S : Specific gravity of liquids

F_p : Piping geometry factor (unitless)

CONCRETE EXAMPLE #20



Valve size	2"	2 1/2"	3"	4"
100% C _v	41	73	114	175

3" VALVE
✓ OK

CONCRETE EXAMPLE #20

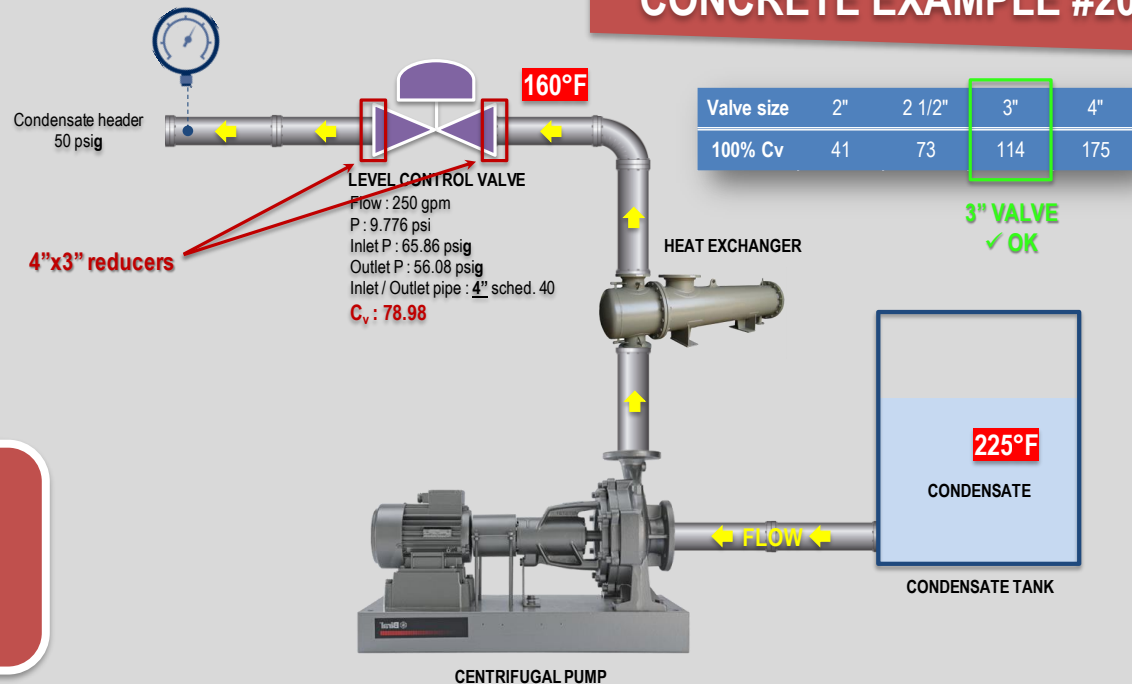
$$F_p = \frac{1}{\sqrt{1 + \frac{\sum K}{890} \left(\frac{C_v}{d_{nom,v}} \right)^2}}$$

$$\sum K = 1.5 \left[1 - \left(\frac{d_{nom,v}}{d_{nom}} \right)^2 \right]^2$$

$d_{nom,v}$: Nominal valve size (in)

d_{nom} : Nominal pipe size (in)

C_v : Flow coefficient of assumed valve size at **100% open**



CONCRETE EXAMPLE #20

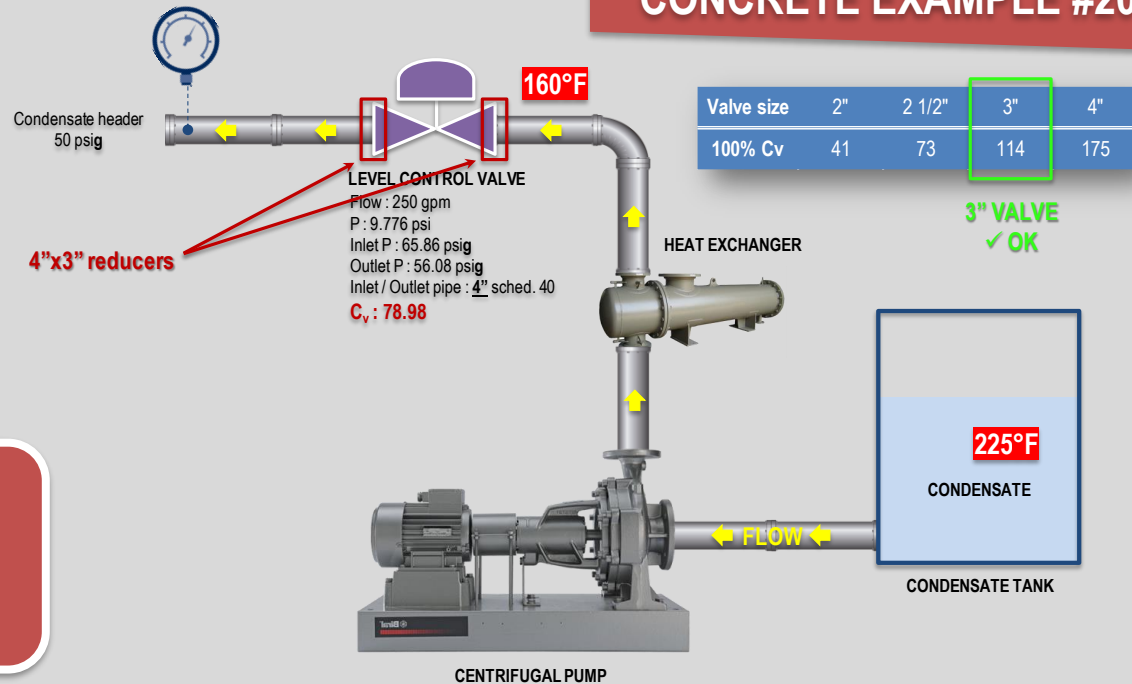
$$F_p = \frac{1}{\sqrt{1 + \frac{\sum K}{890} \left(\frac{C_v}{d_{nom,v}} \right)^2}}$$

$$\sum K = 1.5 \left[1 - \left(\frac{3}{4} \right)^2 \right]^2$$

$d_{nom,v}$: Nominal valve size (in)

d_{nom} : Nominal pipe size (in)

C_v : Flow coefficient of assumed valve size at **100% open**



CONCRETE EXAMPLE #20

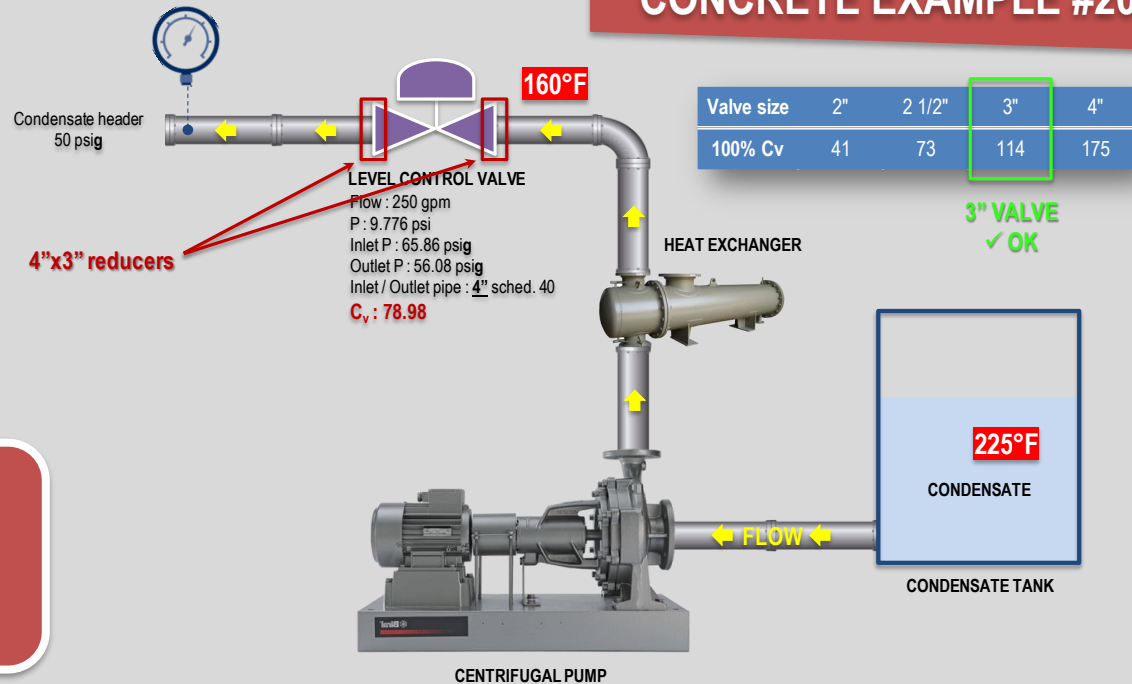
$$F_p = \frac{1}{\sqrt{1 + \frac{\sum K}{890} \left(\frac{C_v}{d_{nom,v}} \right)^2}}$$

$$\sum K = 0.287$$

$d_{nom,v}$: Nominal valve size (in)

d_{nom} : Nominal pipe size (in)

C_v : Flow coefficient of assumed valve size at **100% open**



CONCRETE EXAMPLE #20

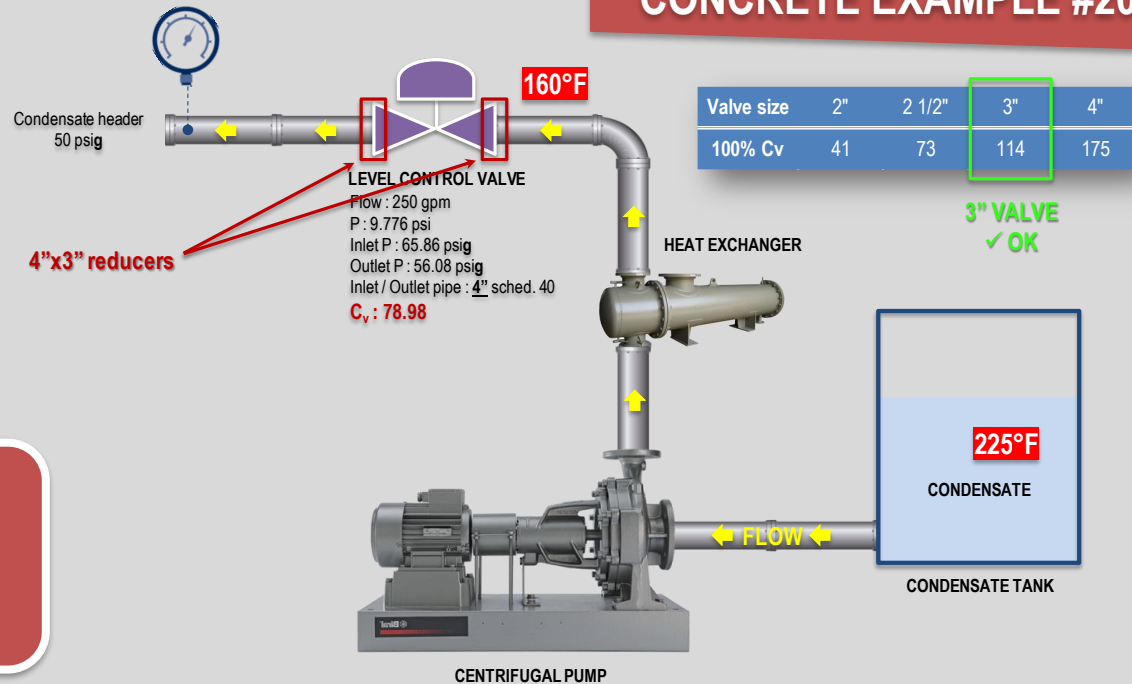
$$F_p = \frac{1}{\sqrt{1 + \frac{0.287}{890} \left(\frac{114}{3^2}\right)^2}}$$

$$\sum K = 0.287$$

$d_{nom, v}$: Nominal valve size (in)

d_{nom} : Nominal pipe size (in)

C_v : Flow coefficient of assumed valve size at **100% open**



CONCRETE EXAMPLE #20

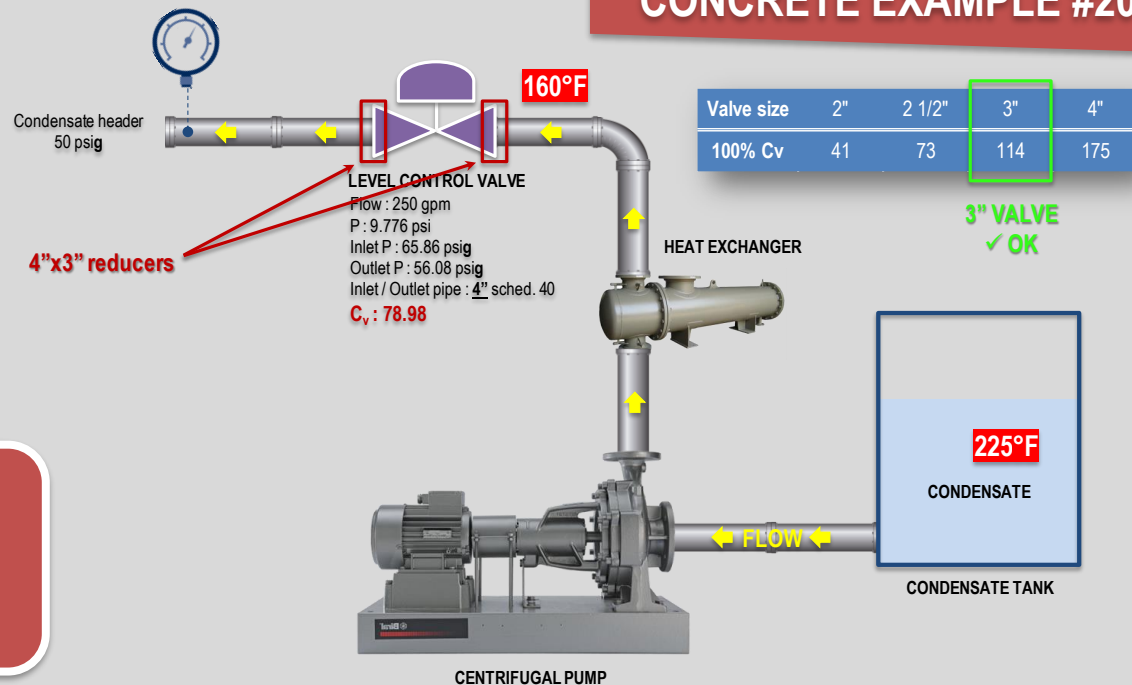
$$F_p = 0.975$$

$$\sum K = 0.287$$

$d_{nom, v}$: Nominal valve size (in)

d_{nom} : Nominal pipe size (in)

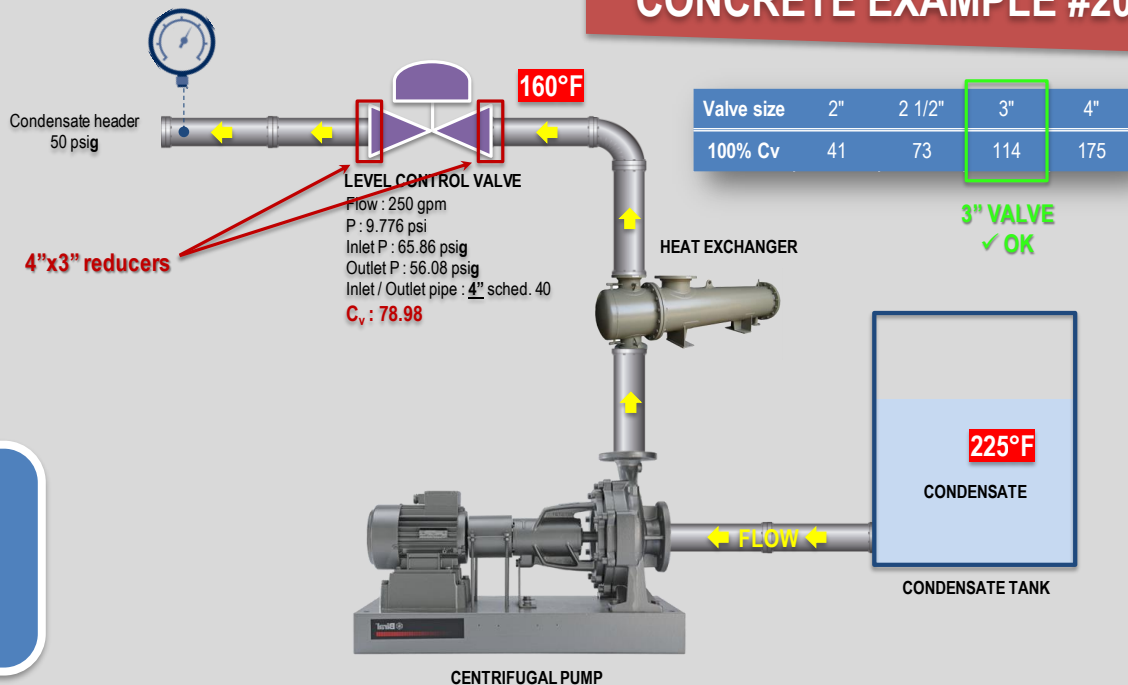
C_v : Flow coefficient of assumed valve size at **100% open**



CONCRETE EXAMPLE #20

$$F_p = 0.975$$

$$C_v = 114 \times 0.975 = 111$$



d_{nom, v} : Nominal valve size (in)

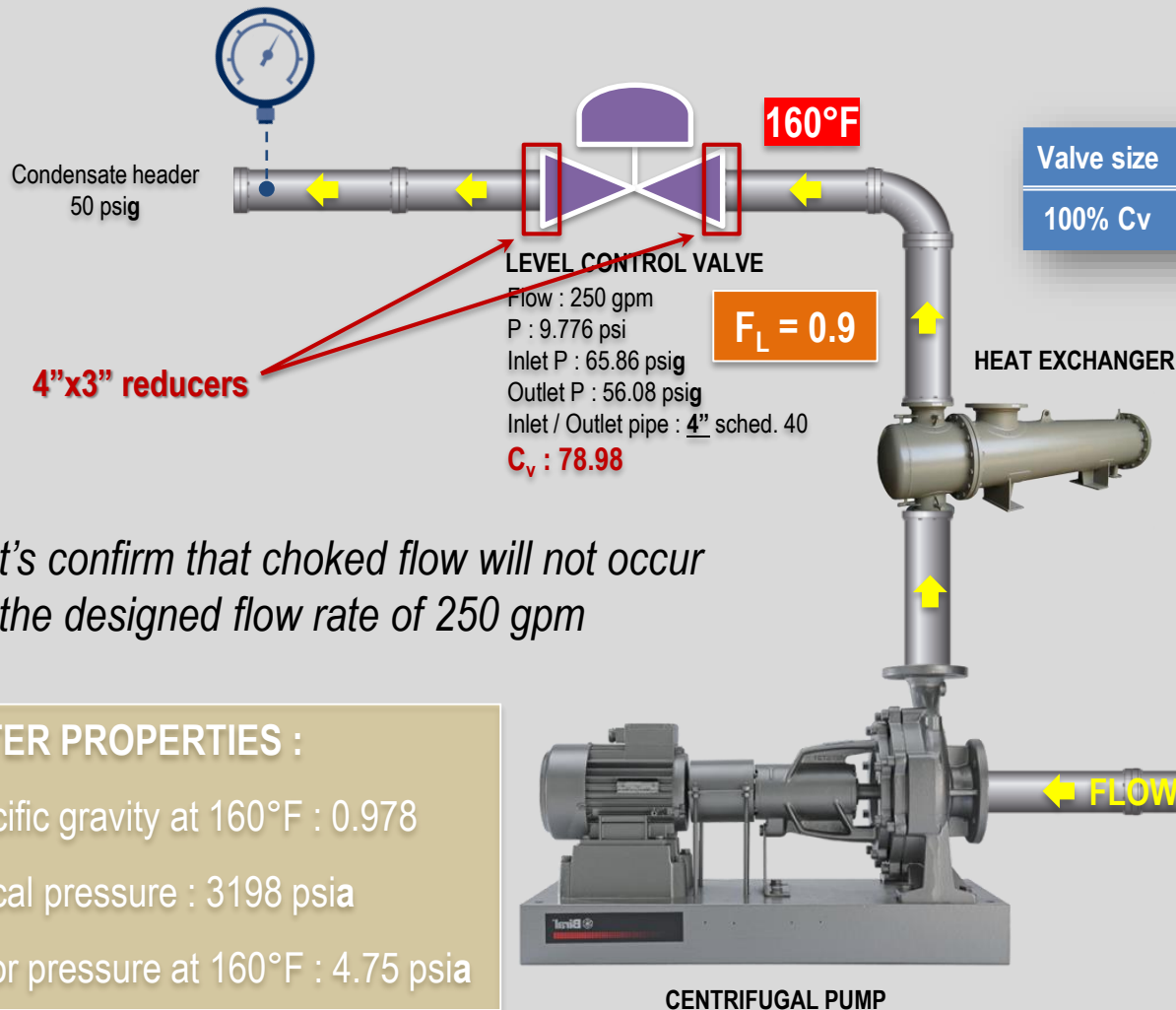
d_{nom} : Nominal pipe size (in)

C_v : Flow coefficient of assumed valve size at **100% open**

CONCRETE EXAMPLE # 21

CONTROL VALVES
CHOKED FLOW CONDITIONS

CONCRETE EXAMPLE #21



Valve size	2"	2 1/2"	3"	4"
100% C _v	41	73	114	175

**3" VALVE
✓ OK**

- Let's confirm that choked flow will not occur at the designed flow rate of 250 gpm

WATER PROPERTIES :

Specific gravity at 160°F : 0.978

Critical pressure : 3198 psia

Vapor pressure at 160°F : 4.75 psia

MAXIMUM FLOW RATE

at which choking occurs

$$Q_{\max} = F_L C_v \sqrt{\frac{P_1 - F_F P_v}{S}}$$

F_L : Liquid pressure recovery factor (unitless)

C_v : Flow coefficient for valves or piping components

P_1 : Absolute upstream pressure (psia)

F_F : Liquid critical pressure ratio factor (unitless)

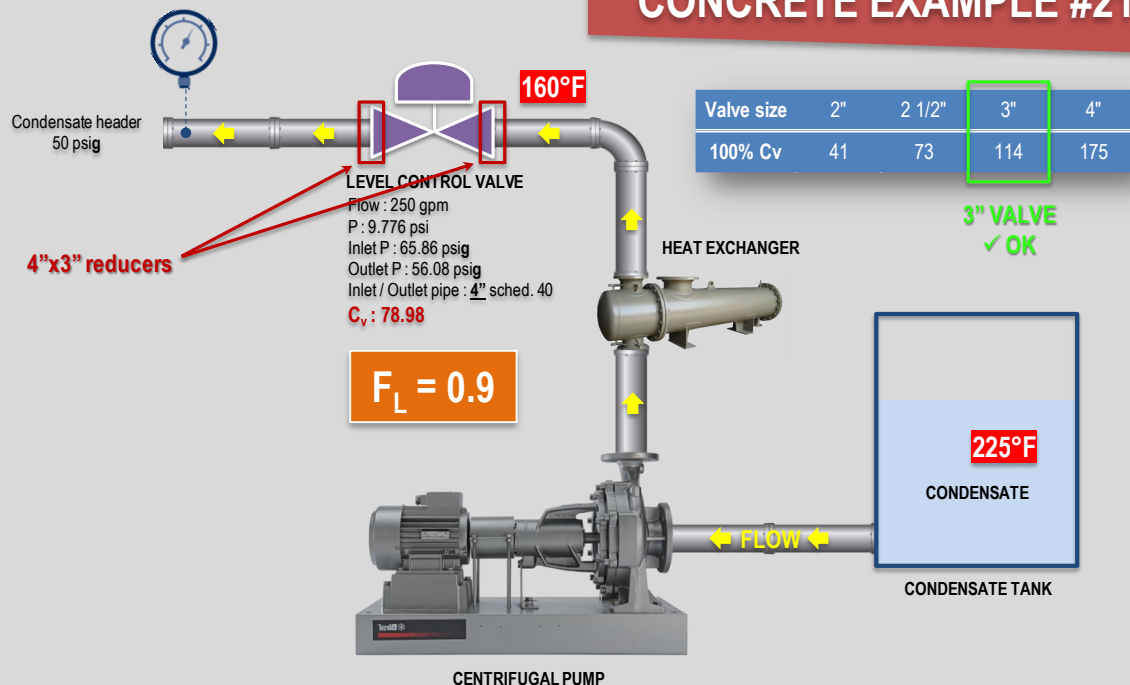
P_v : Absolute fluid vapor pressure (psia)

S : Specific gravity of liquids

F_{LP} : Combined piping geometry and liquid pressure recovery factor (unitless)

F_P : Piping geometry factor (unitless)

CONCRETE EXAMPLE #21



WATER PROPERTIES :

Specific gravity at 160°F : 0.978

Critical pressure : 3198 psia

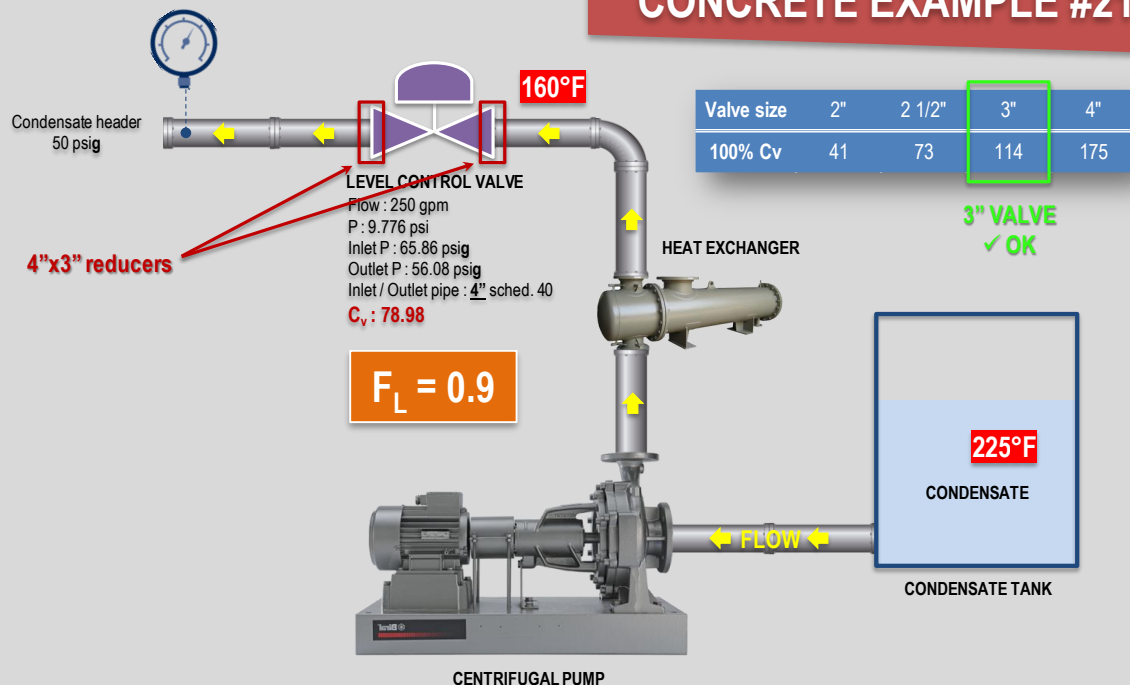
Vapor pressure at 160°F : 4.75 psia

MAXIMUM FLOW RATE

at which choking occurs

$$Q_{\max} = F_L C_v \sqrt{\frac{P_1 - F_F P_v}{S}}$$

$$F_F = 0.96 - 0.28 \sqrt{\frac{P_v}{P_c}}$$



WATER PROPERTIES :

Specific gravity at 160°F : 0.978

Critical pressure : 3198 psia

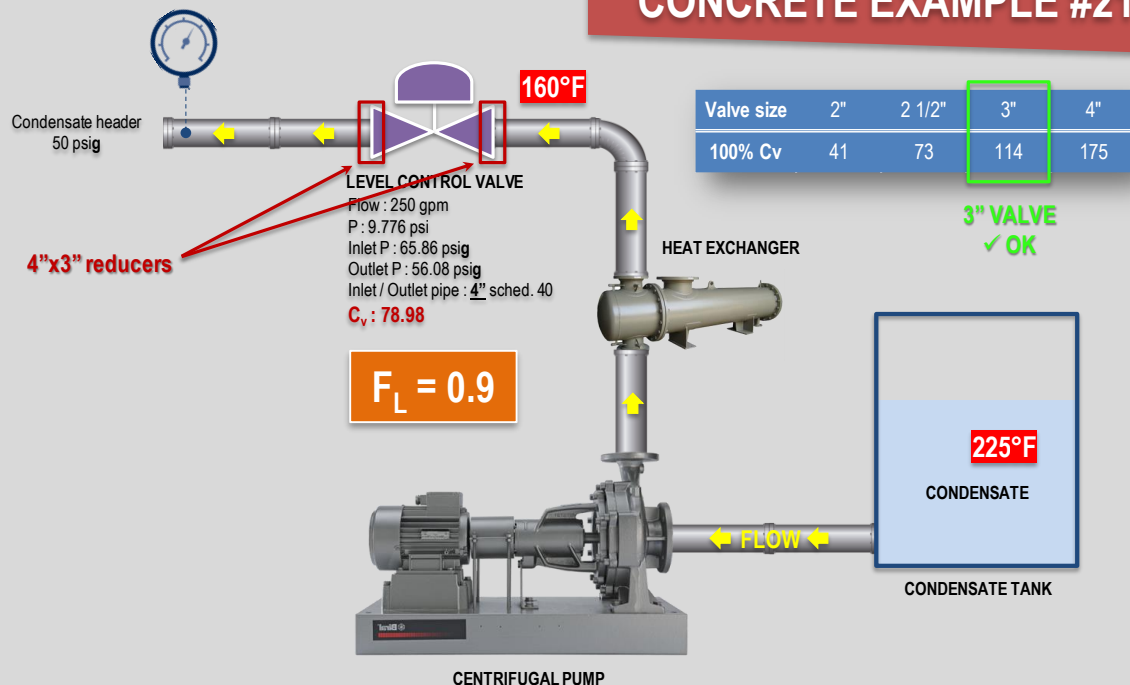
Vapor pressure at 160°F : 4.75 psia

MAXIMUM FLOW RATE

at which choking occurs

$$Q_{\max} = F_L C_v \sqrt{\frac{P_1 - F_F P_v}{S}}$$

$$F_F = 0.95$$



WATER PROPERTIES :

Specific gravity at 160°F : 0.978

Critical pressure : 3198 psia

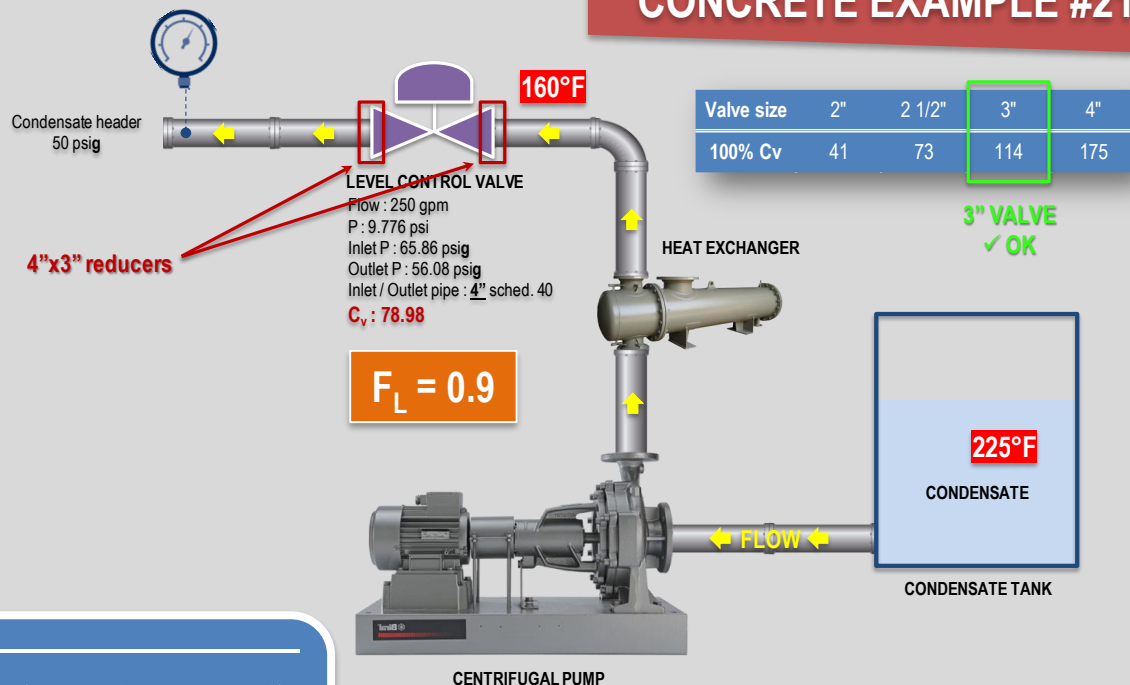
Vapor pressure at 160°F : 4.75 psia

MAXIMUM FLOW RATE

at which choking occurs

$$Q_{\max} = F_L C_v \sqrt{\frac{P_1 - F_F P_v}{S}}$$

$$Q_{\max} = 0.9 \times 78.98 \times \sqrt{\frac{80.6 - (0.95 \times 4.75)}{0.978}}$$



WATER PROPERTIES :

Specific gravity at 160°F : 0.978

Critical pressure : 3198 psia

Vapor pressure at 160°F : 4.75 psia

MAXIMUM FLOW RATE

at which choking occurs

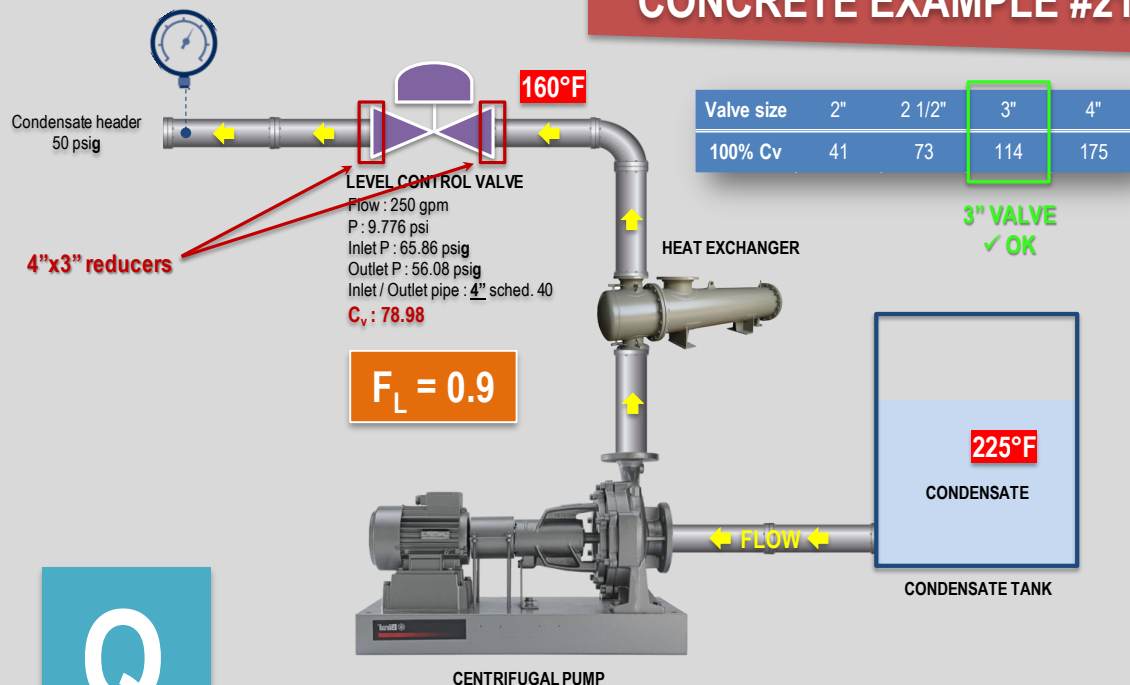
$$Q_{\max} = F_L C_v \sqrt{\frac{P_1 - F_F P_v}{S}}$$

$$Q_{\max} = 626 \text{ gpm}$$

>

Q
250 gpm

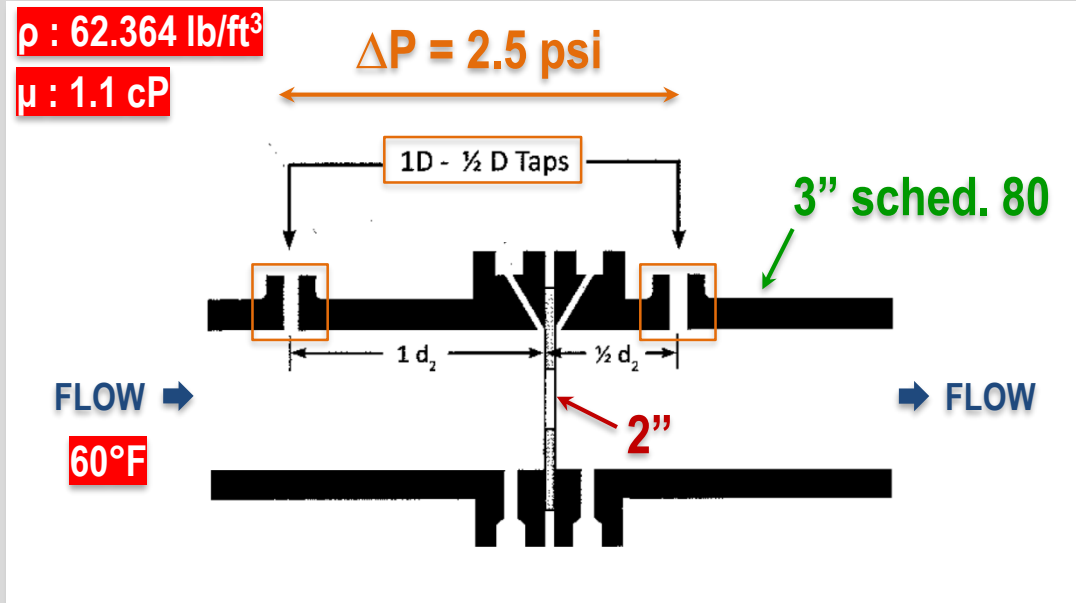
CONCRETE EXAMPLE #21



CONCRETE EXAMPLE # 22

FLOW METERS

ORIFICE FLOW RATE CALCULATION



- *Let's calculate the flow rate in gallons per minute (gpm)*

- Let's calculate the flow rate in gallons per minute (gpm)

$$Q = 235.6 d_{\text{orifice}}^2 C \sqrt{\frac{\Delta P}{\rho}}$$

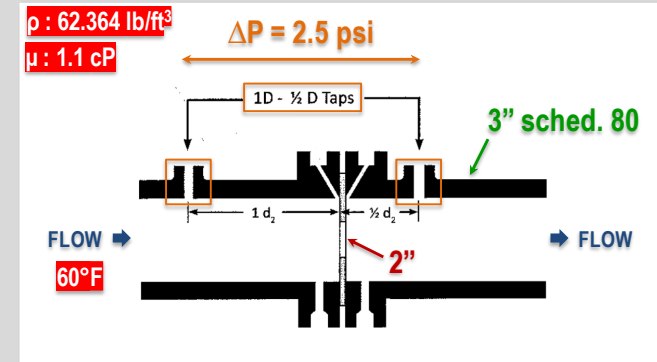
Q : Rate of flow at flowing conditions (gpm)

C : Flow coefficient (unitless)

d_{orifice} : Orifice internal diameter (in)

ΔP : Differential pressure (psi)

ρ : Weight density of fluid (lb/ft³)



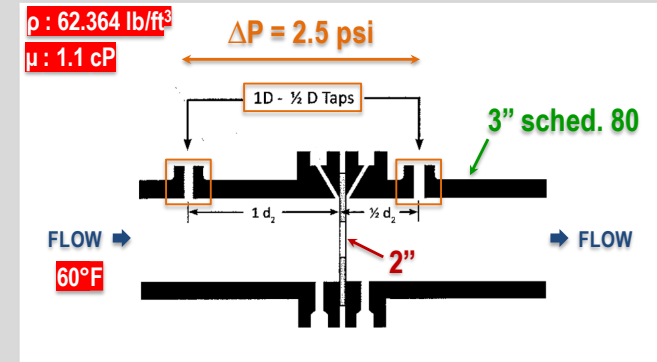
- Let's calculate the flow rate in gallons per minute (gpm)

$$Q = 235.6 d_{\text{orifice}}^2 C \sqrt{\frac{\Delta P}{\rho}}$$

Water weight density at 60°F (ρ) : 62.364 lb/ft³

3" schedule 80 pipe internal diameter : 2.9 in

Flow coefficient (C) "iteration #1" : 0.7



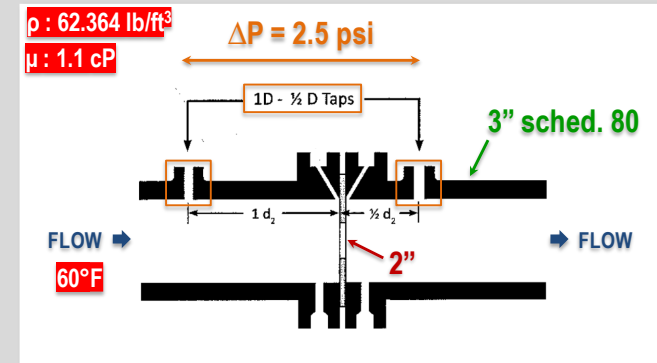
- Let's calculate the flow rate in gallons per minute (gpm)

$$Q = 235.6 \times 2^2 \times 0.7 \times \sqrt{\frac{2.5}{62.364}}$$

Water weight density at 60°F (ρ) : 62.364 lb/ft³

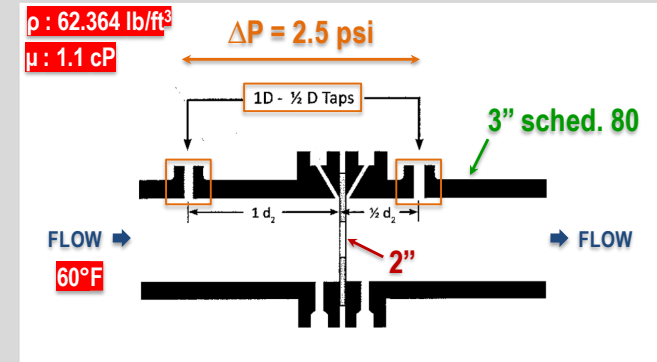
3" schedule 80 pipe internal diameter : 2.9 in

Flow coefficient (C) "iteration #1" : 0.7



- Let's calculate the flow rate in gallons per minute (gpm)

$$Q = 132 \text{ gpm}$$



Water weight density at 60°F (ρ) : 62.364 lb/ft³

3" schedule 80 pipe internal diameter : 2.9 in

Flow coefficient (C) "iteration #1" : 0.7

Reynolds number (Re) : 131000



Flow coefficient (C) "iteration #2" : **0.695**

- Let's calculate the flow rate in gallons per minute (gpm)

$$Q = 235.6 d_{\text{orifice}}^2 C \sqrt{\frac{\Delta P}{\rho}}$$

Water weight density at 60°F (ρ) : 62.364 lb/ft³

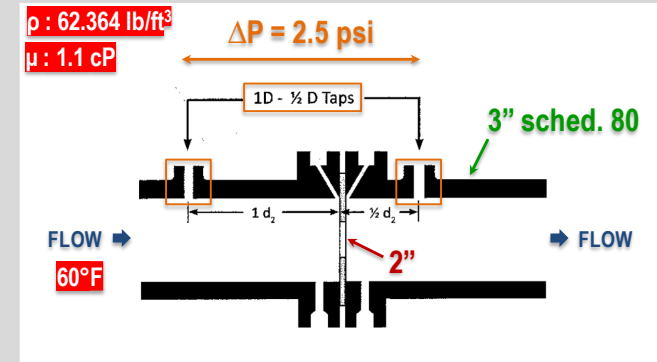
3" schedule 80 pipe internal diameter : 2.9 in

Flow coefficient (C) "iteration #1" : 0.7

Reynolds number (Re) : 131000



Flow coefficient (C) "iteration #2" : **0.695**



- Let's calculate the flow rate in gallons per minute (gpm)

$$Q = 235.6 \times 2^2 \times 0.695 \times \sqrt{\frac{2.5}{62.364}}$$

Water weight density at 60°F (ρ) : 62.364 lb/ft³

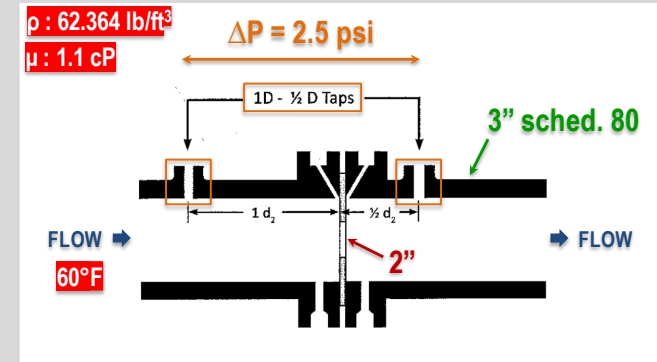
3" schedule 80 pipe internal diameter : 2.9 in

Flow coefficient (C) "iteration #1" : 0.7

Reynolds number (Re) : 131000

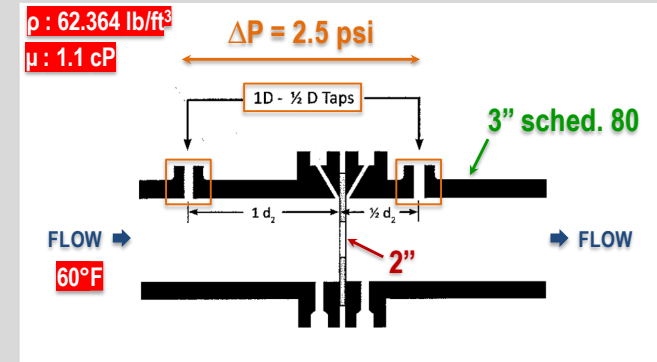


Flow coefficient (C) "iteration #2" : **0.695**



- Let's calculate the flow rate in gallons per minute (gpm)

$$Q = 131 \text{ gpm}$$



Water weight density at 60°F (ρ) : 62.364 lb/ft³

3" schedule 80 pipe internal diameter : 2.9 in

Flow coefficient (C) "iteration #1" : 0.7

Reynolds number (Re) : 131000



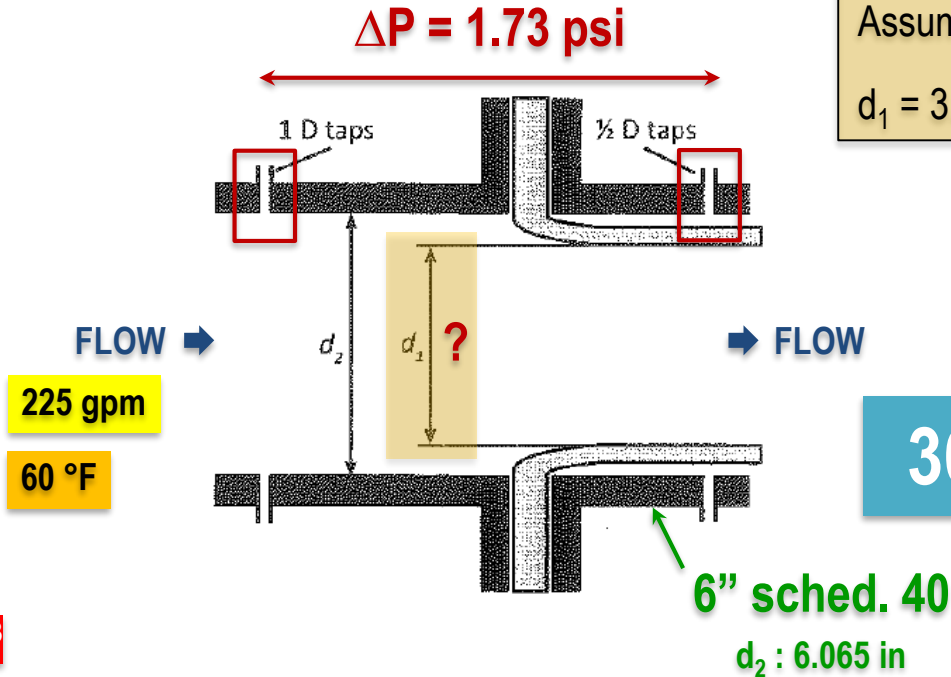
Flow coefficient (C) "iteration #2" : **0.695**

CONCRETE EXAMPLE # 23

FLOW METERS

NOZZLE SIZING CALCULATION

LONG RADIUS NOZZLE



Iteration #1 :

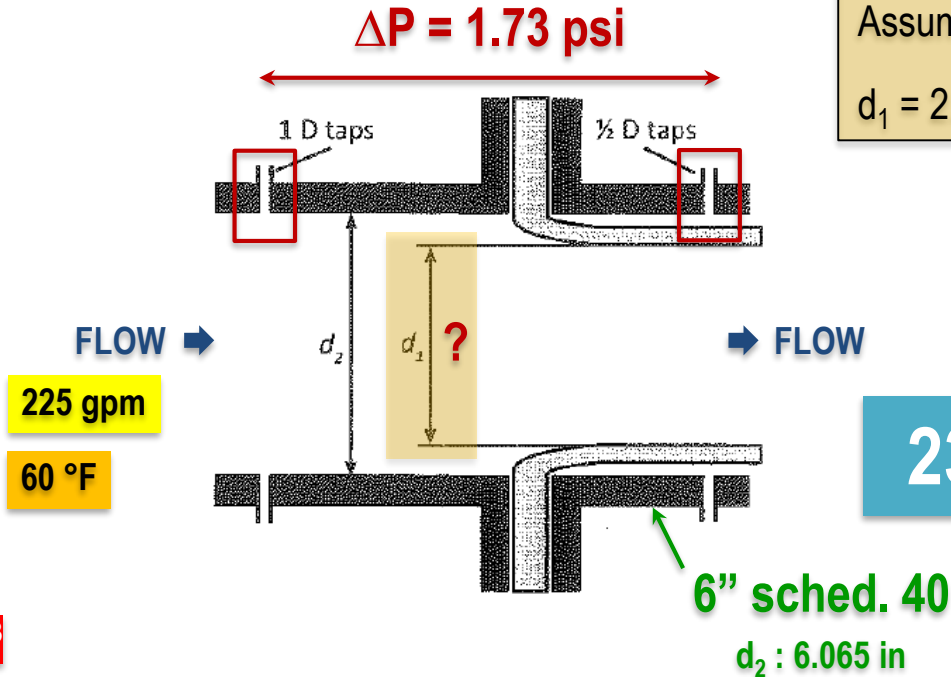
Assume $\beta = 0.5$

$d_1 = 3.033$ in

Q

369 gpm

LONG RADIUS NOZZLE



Iteration #2 :

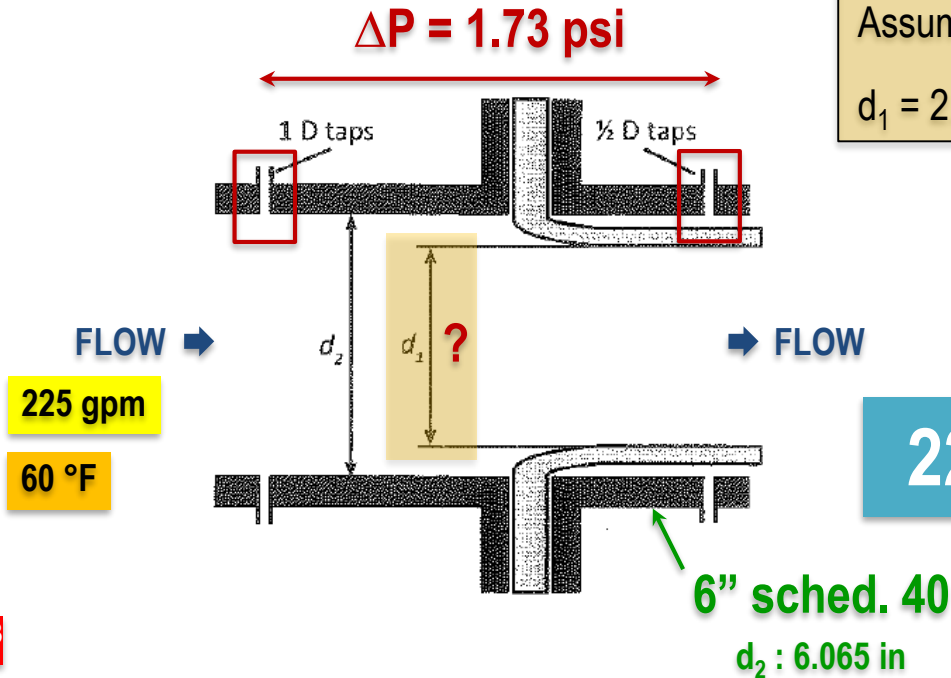
Assume $\beta = 0.4$

$d_1 = 2.426$ in

$\rho : 62.364$ lb/ft³

$\mu : 1.1$ cP

LONG RADIUS NOZZLE



Iteration #3 :

Assume $\beta = 0.394$

$d_1 = 2.39 \text{ in}$

Q

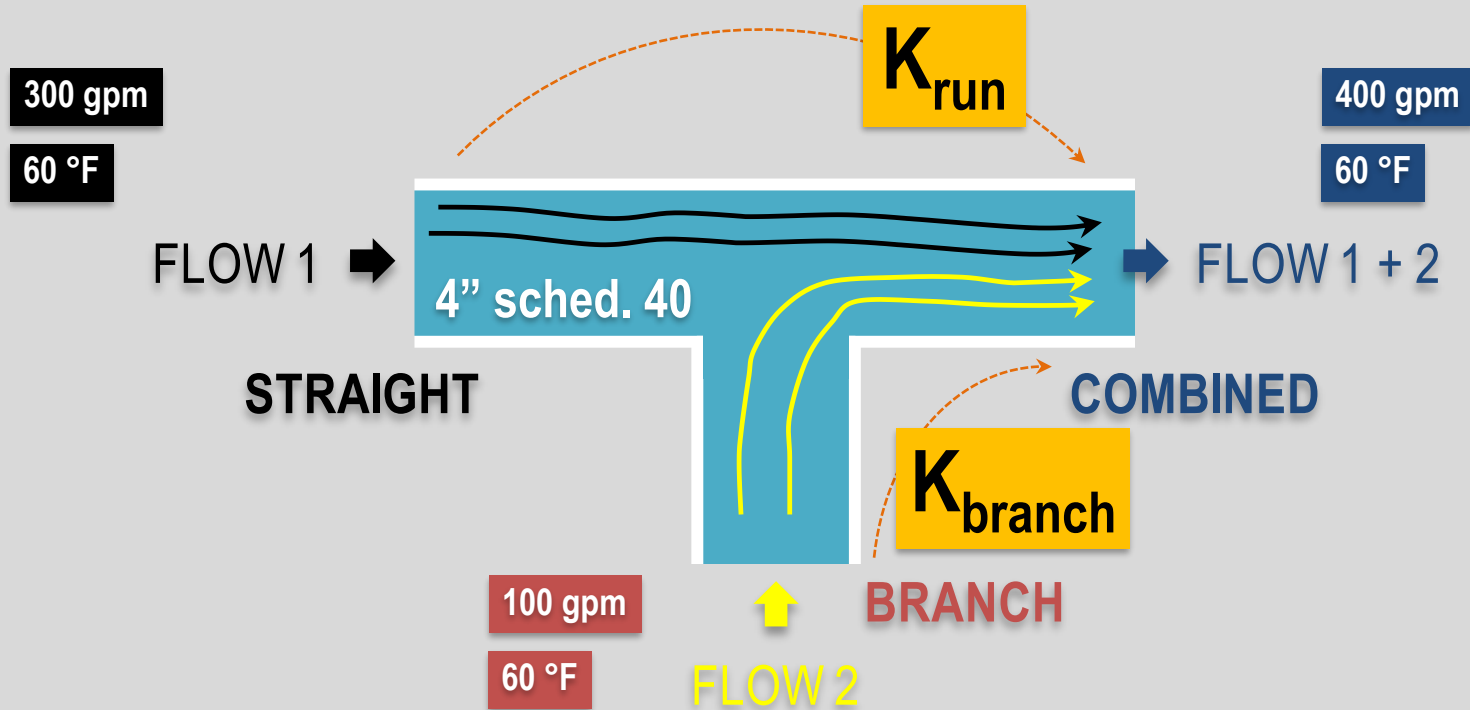
225 gpm

$\rho : 62.364 \text{ lb/ft}^3$

$\mu : 1.1 \text{ cP}$

CONCRETE EXAMPLE # 24

TEES AND WYES
HYDRAULIC RESISTANCE
OF A **CONVERGING** TEE



- Let's find the resistance coefficients K_{run} and K_{branch} along with the head loss across each flow path

K_{branch}

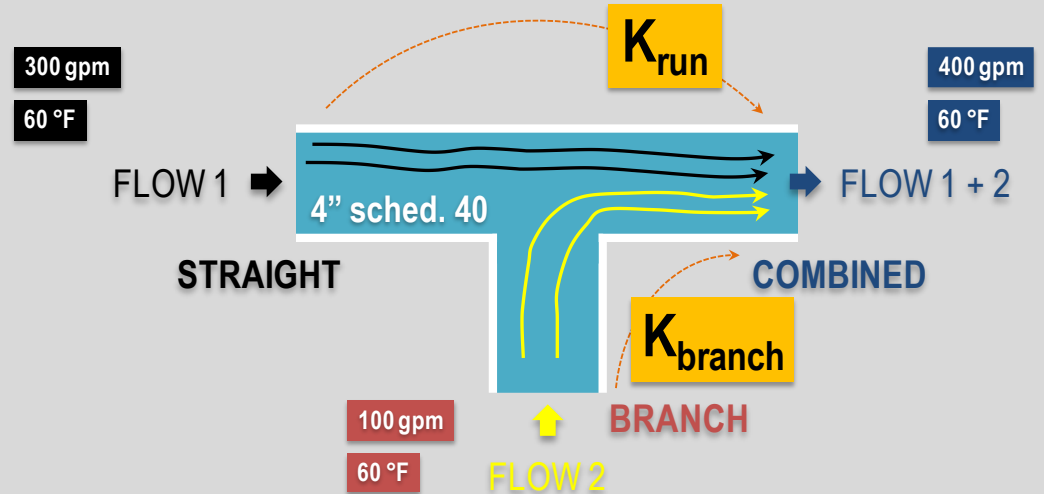
-0.042

K_{run}

0.32

$$h_{L,\text{branch}} = K_{\text{branch}} \frac{v^2}{2g}$$

$$h_{L,\text{run}} = K_{\text{run}} \frac{v^2}{2g}$$



- Let's find the resistance coefficients K_{run} and K_{branch} along with the head loss across each flow path

K_{branch}

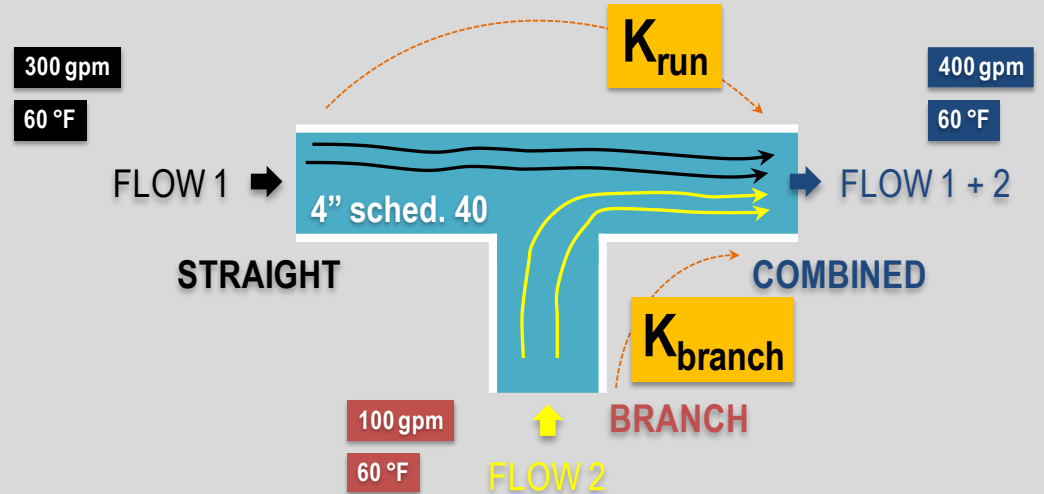
-0.042

K_{run}

0.32

$$h_{L,\text{branch}} = -0.042 \frac{10.08^2}{2 \times 32.2}$$

$$h_{L,\text{run}} = 0.32 \frac{10.08^2}{2 \times 32.2}$$



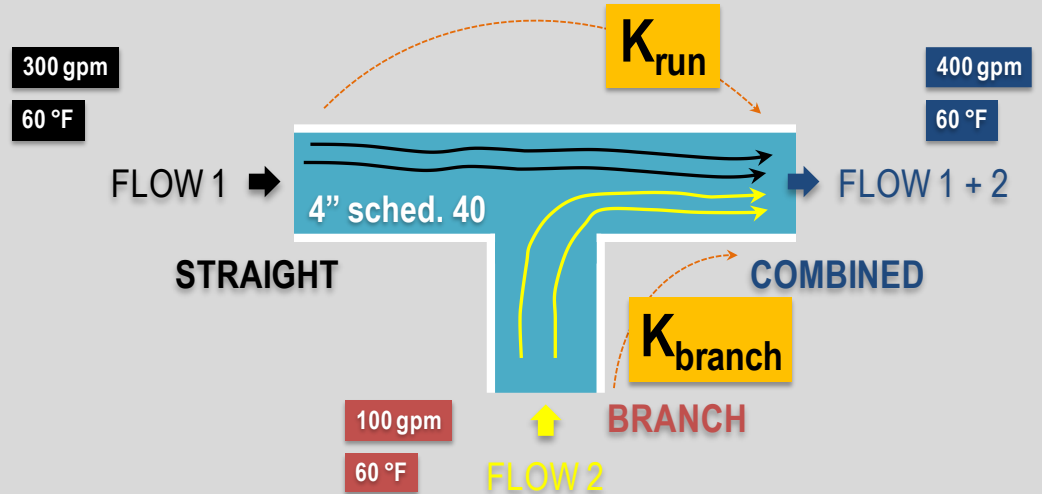
- Let's find the resistance coefficients K_{run} and K_{branch} along with the head loss across each flow path

$$K_{\text{branch}} = -0.042$$

$$K_{\text{run}} = 0.32$$

$$h_{L,\text{branch}} = -0.066 \text{ ft}$$

$$h_{L,\text{run}} = 0.513 \text{ ft}$$



- Let's find the resistance coefficients K_{run} and K_{branch} along with the head loss across each flow path