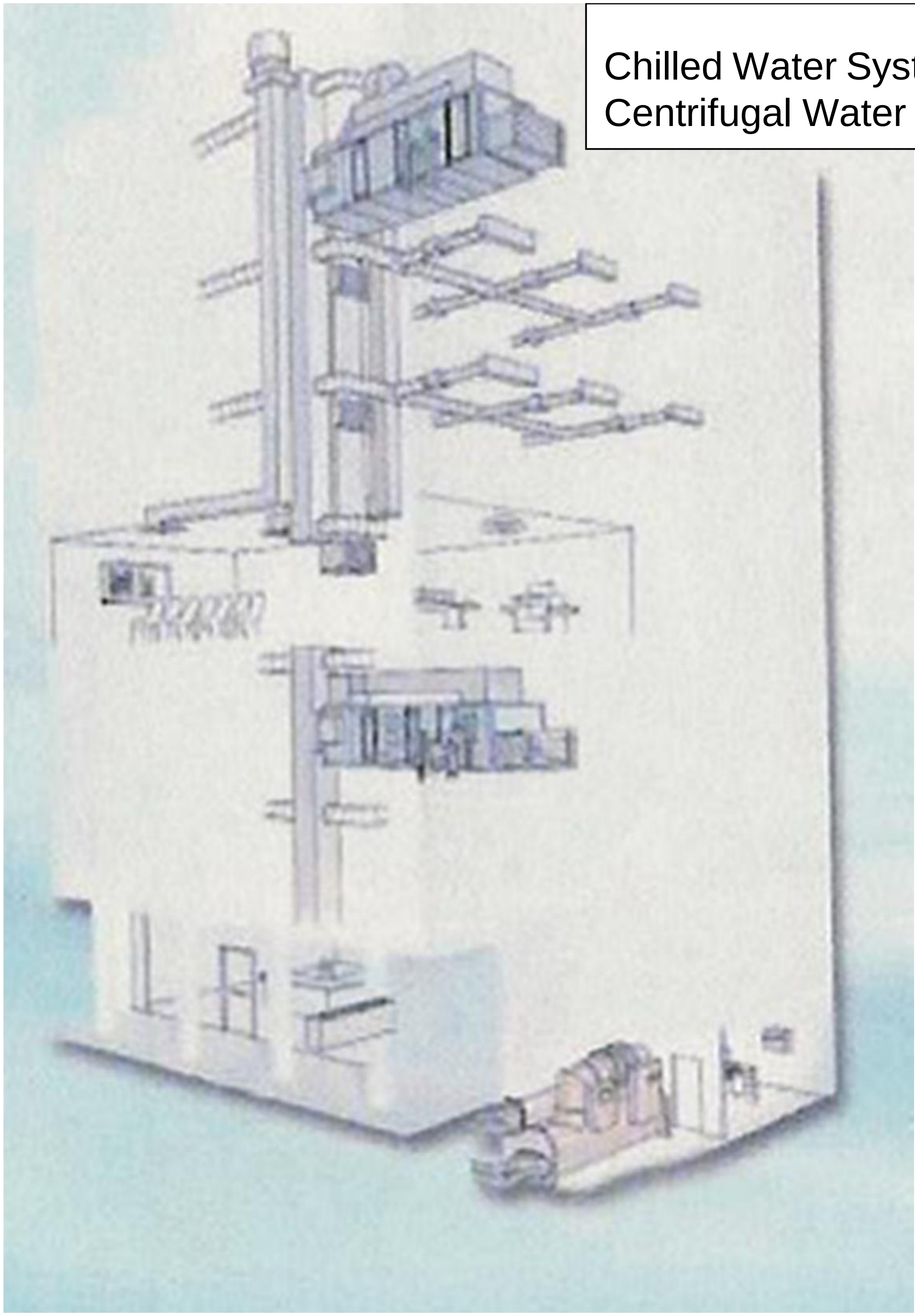
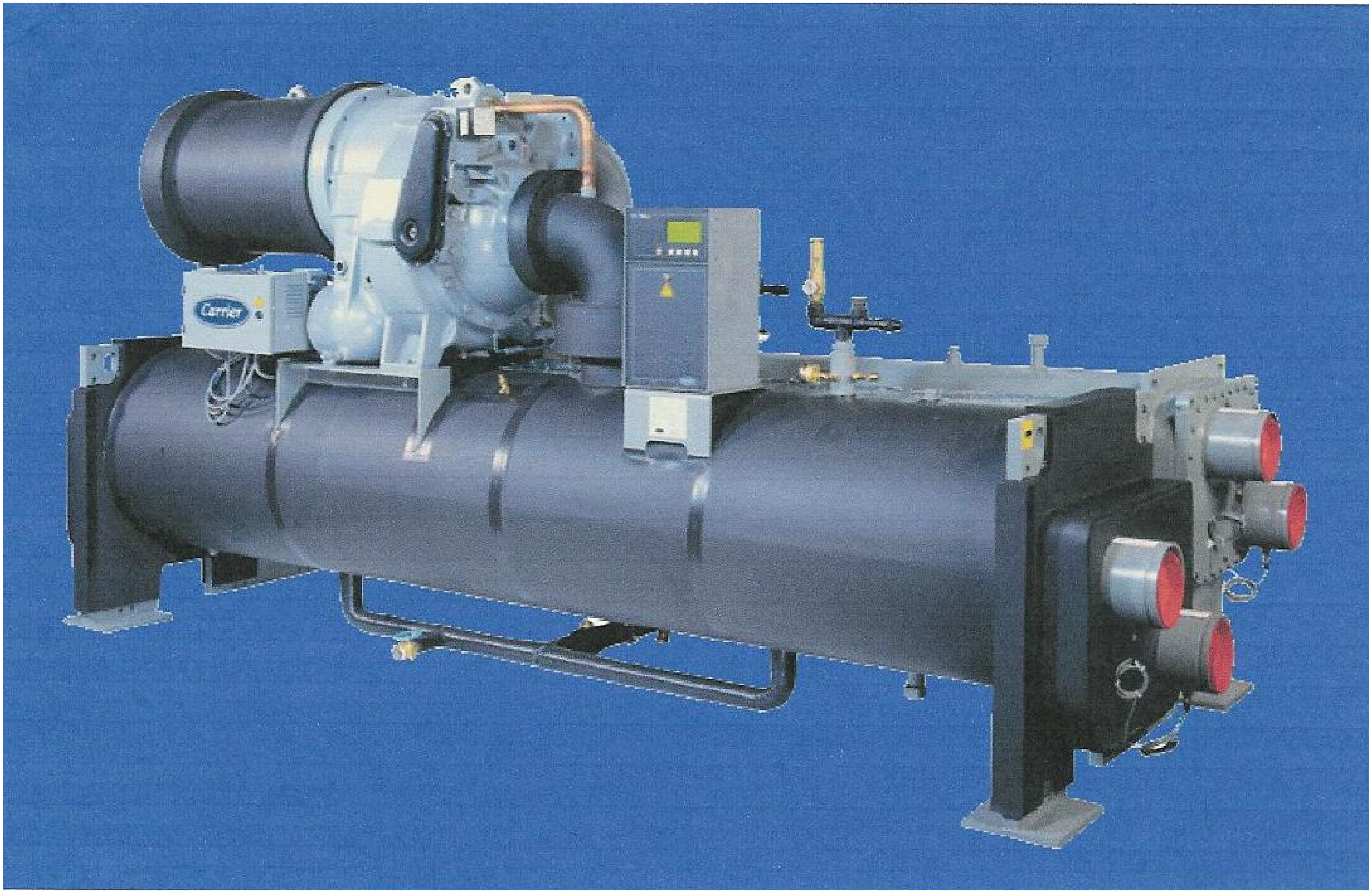
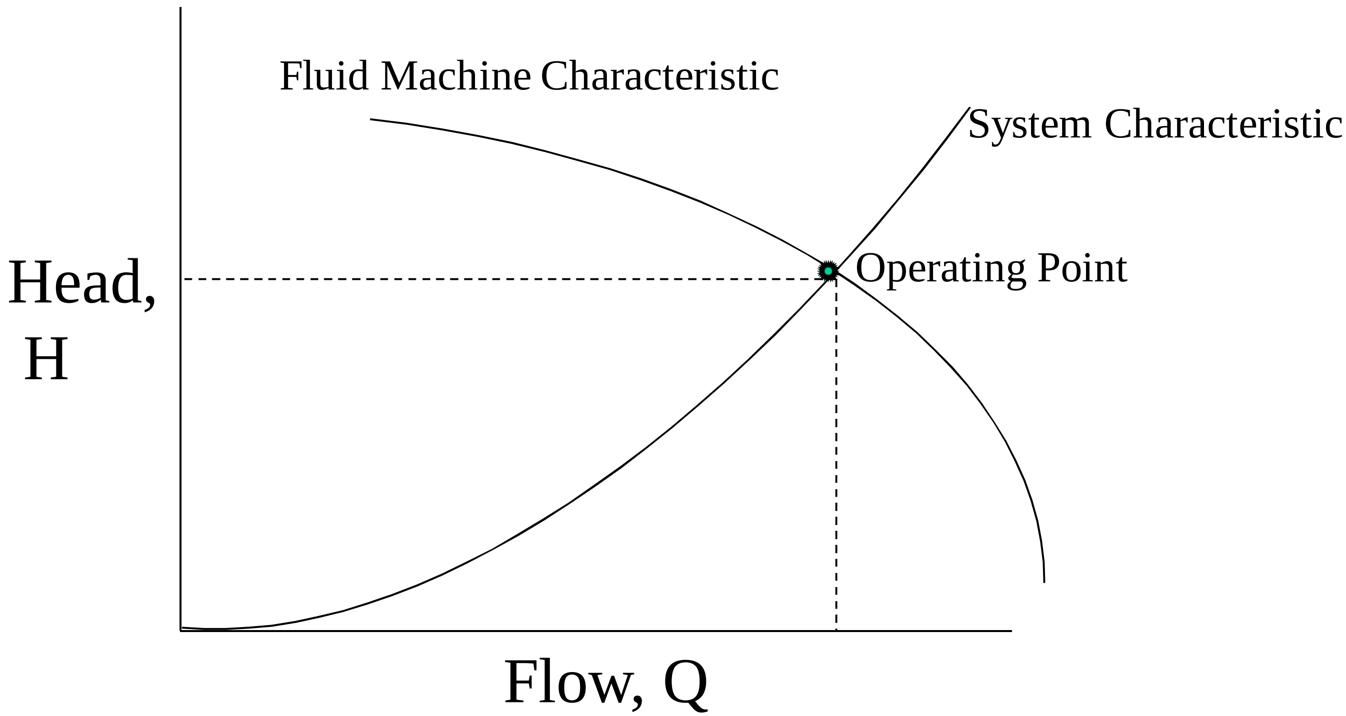
Chilled Water System
Centrifugal Water Chiller



Centrifugal Water Chiller



# FLUID SYSTEM CHARACTERISTICS




Energy (head) is put into the system fluid by the fluid machine in the form of velocity and pressure.

Energy (head) is removed from the system fluid by friction in the piping or duct work.

EQUATION OF MOTION

one dimensional, steady

$$\text{Ɉ}\, u \frac{du}{dx} = -\frac{dp}{dx} + \varepsilon \frac{d^2u}{dx^2}$$

Substitute dimensionl ess parameters, U, X, P

$$U = \frac{u}{V} \quad u = VU \quad u\,du = V^2\, U\,dU \quad d^2u = V\, d^2U$$

$$X = \frac{x}{L} \quad x = LX \quad dx = L\,dX \quad dx^2 = L^2 dX^2$$

$$P = \frac{p}{P_o} \quad p = P_o P \quad dp = P_o\, dP$$

$$\left(\frac{\text{Ɉ}\, V^2}{L}\right) U \frac{dU}{dX} = -\left(\frac{P_o}{L}\right)\frac{dP}{dX} + \left(\frac{\varepsilon V}{L^2}\right)\frac{d^2U}{dX^2}$$

divide by $\frac{\text{Ɉ}\, V^2}{L}$,

$$U \frac{dU}{dX} = -\left(\frac{P_o}{\text{Ɉ}\, V^2}\right)\frac{dP}{dX} + \left(\frac{1}{\frac{\text{Ɉ}\, VL}{\varepsilon}}\right)\frac{d^2U}{dX^2}$$

$\frac{\text{Ɉ}\, VL}{\varepsilon}$ is the dimensionl ess parameter Reynolds Nu mber

# FLUID MACHINE DIMENSIONLESS PARAMETERS

If the full set of equations for fluid machine,

Energy Balance - First Law
Mass balance - continuity equation
Equations of motion F=mass x acceleration

are non-dimensionalized 6 dimensionless parameters result.

If the machine variables are changes so that 5 of these dimensionless parameters remain constant, the 6th parameter will also remain constant.

In the operation of a pump or fan Mach Number, and Specific Heat Ratio remain constant and Reynolds Number changes very little.

If the Specific Speed and Specific Diameter of a fluid machine remain the same even though rotational speed, head and flow many change, the same efficiency will be achieved.

$$\text{Specific Speed } N_s = \frac{NQ^{.5}}{H^{.75}}$$

$$\text{Specific Diameter} = \frac{DH^{.25}}{Q^{.5}}$$

$$N = \text{rotauional speed}$$
$$Q = \text{volume flow}$$
$$H = \text{head}$$
$$D = \text{diameter}$$

$$\text{Mach Number } M = \frac{\text{Velocity}}{\text{Sonic Velocity}}$$

$$\text{Reynolds Number} = \frac{\varepsilon VL}{J}$$

$$V = \text{velocity}$$
$$\varepsilon = \text{viscosity}$$
$$J = \text{density}$$

$$\text{Specific Heat Ratio } k = \frac{c_p}{c_v}$$

Efficiency

$$d_{compressor} = \frac{\text{Ideal Work}}{\text{Actual Work}}$$

$$d_{compressor} = \frac{\text{Actual Work}}{\text{Ideal Work}}$$

# PUMP SPECIFIC SPEED SPECIFIC DIAMETER DIAGRAM

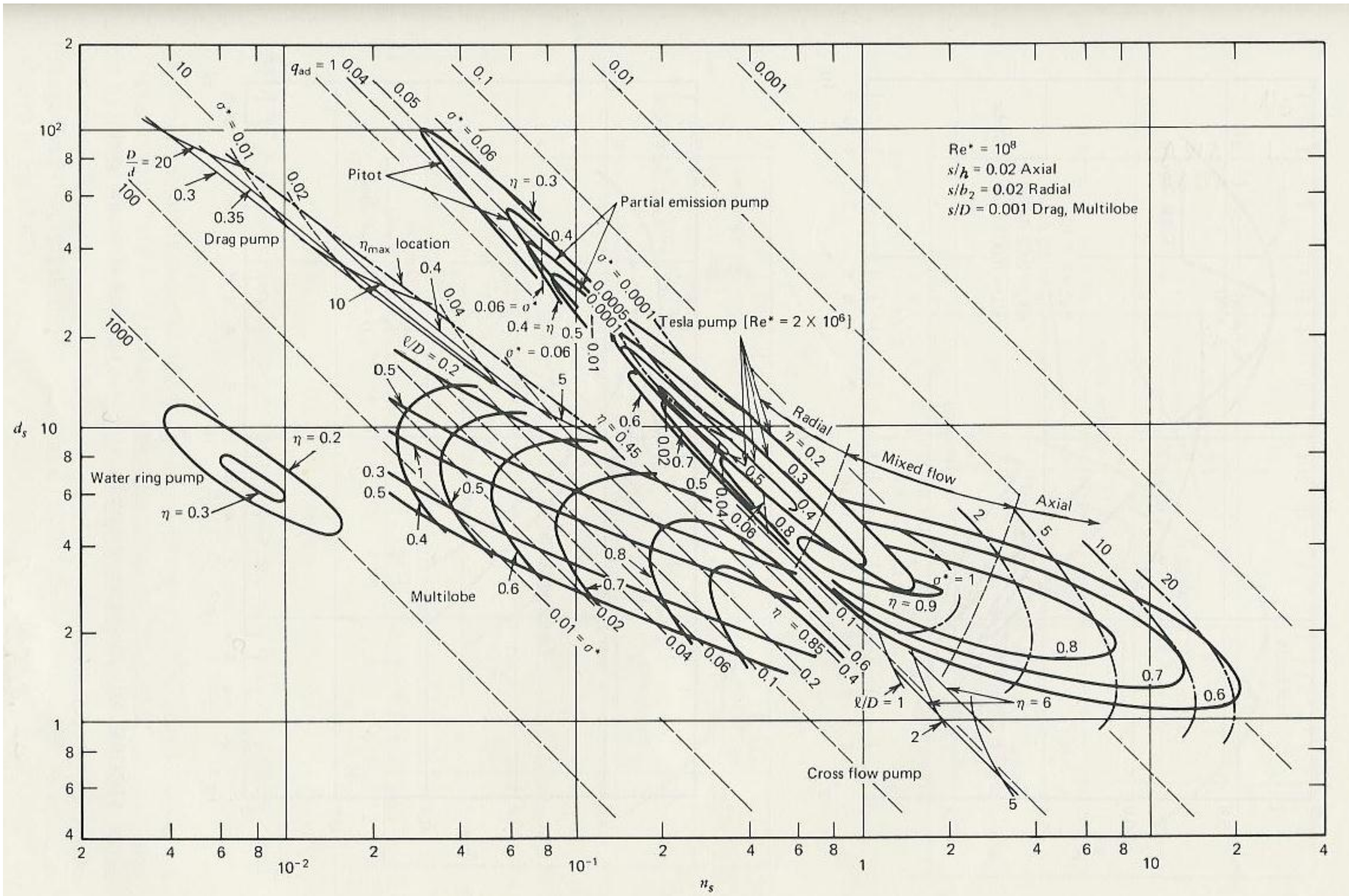



**FIGURE 3.8** $n_s d_s$ diagram for single stage pumps.

1) Similar geometry+Constant Specific Speed and Specific Diameter = Same Efficiency

2) Each machine type has an optimum Specific Speed for maximum efficiency.

# MACHINERY AFFINITY LAWS

$$N_S = \text{CONSTANT},\ D_S = \text{CONSTANT},\ \Rightarrow d = \text{CONSTANT}$$

$$\text{SPECIFIC DIAMETER, } D_s = \frac{DH^{.75}}{Q^{.25}} = \text{CONSTANT}$$

$$\frac{D_0 H_0^{\ .75}}{Q_0^{\ .25}} = \frac{D_1 H_1^{\ .75}}{Q_1^{\ .25}}$$

$$\left(\frac{Q_1}{Q_0}\right)^{.5} = \frac{D_{`}}{D_0}\left(\frac{H_1}{H_0}\right)^{.25}$$

$$\left(\frac{Q_1}{Q_0}\right)^{.5} = \frac{D_{`}}{D_0}\left(\left(\frac{N_1}{N_0}\right)^{4}\left(\frac{D_1}{D_0}\right)^{4}\right)^{.25}$$

$$\frac{Q_1}{Q_0} = \left(\frac{D_{`}}{D_0}\right)^{3}\left(\frac{N_1}{N_0}\right)$$

for the same impeller, $D_0 = D$

$$\mathbf{\frac{Q_1}{Q_0} = \left(\frac{N_1}{N_0}\right)}$$

$$\text{POWER} = Q \times H$$

$$\frac{\text{Power}_1}{\text{Power}_2} = \left(\frac{Q_1}{Q_0}\right)\left(\frac{H_1}{H_0}\right) = \left(\frac{N_1}{N_0}\right)\left(\frac{N_1}{N_0}\right)^{2}$$

$$\mathbf{\frac{Power_1}{Power_2} = \left(\frac{N_1}{N_0}\right)^{3}}$$

$$\text{SPECIFIC SPEED, } N_s = \frac{NQ^{.25}}{Q^{.5}} = \text{CONSTANT}$$

$$\frac{N_0 Q_0^{\ .25}}{Q_0^{\ .5}} = \frac{N_1 Q_1^{\ .25}}{Q_1^{\ .5}}$$

$$\left(\frac{Q_1}{Q_0}\right)^{.5} = \frac{N_{0`}}{N_1}\left(\frac{H_1}{H_0}\right)^{.75}$$

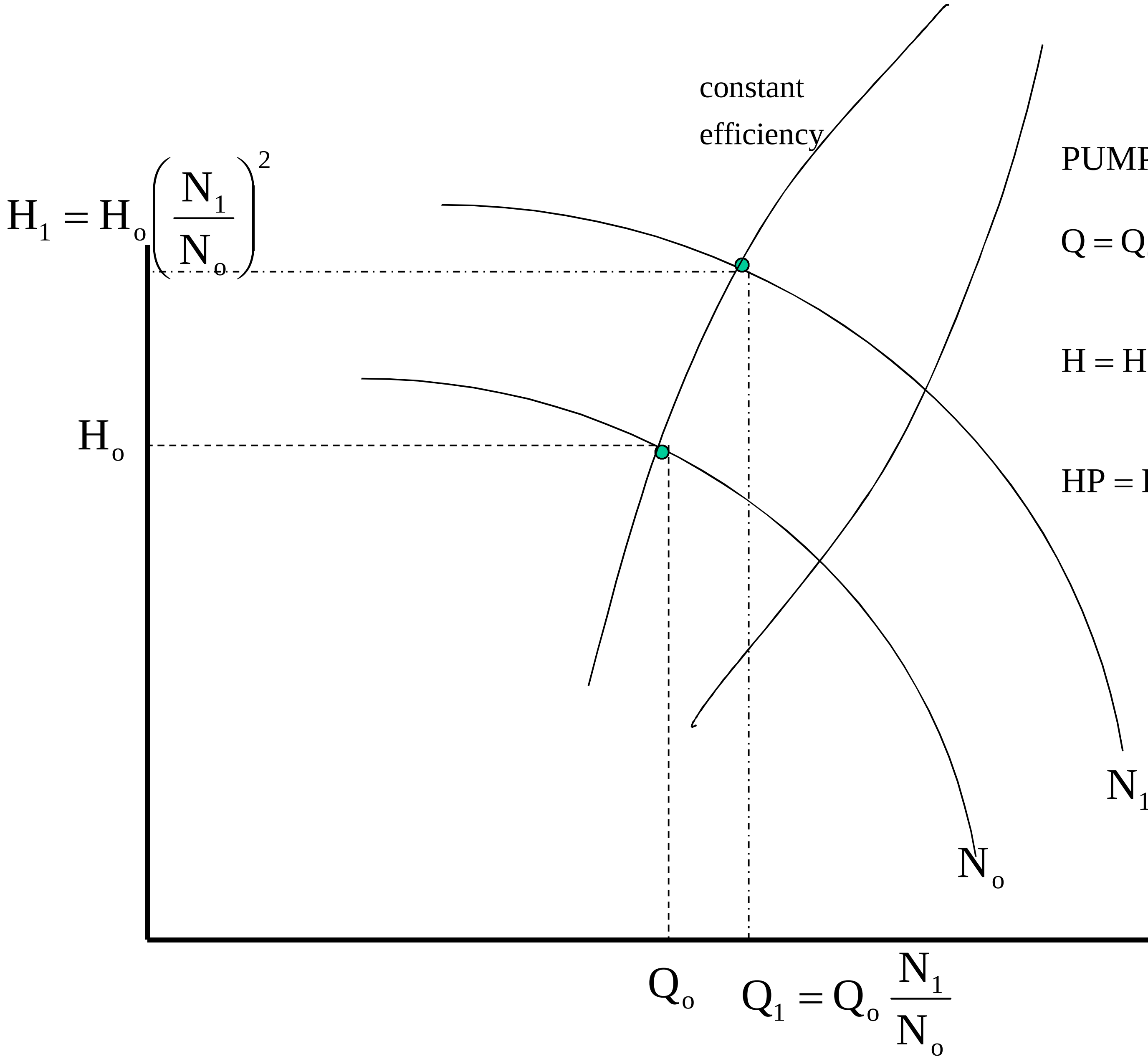
$$\frac{D_1}{D_0}\left(\frac{H_1}{H_0}\right)^{.25} = \frac{N_{`}}{N_0}\left(\frac{H_1}{H_0}\right)^{.75}$$

$$\left(\frac{H_1}{H_0}\right)^{.5} = \left(\frac{N_1}{N_0}\right)\left(\frac{D_1}{D_0}\right)$$

$$\left(\frac{H_1}{H_0}\right)^{.5} = \left(\frac{N_1}{N_0}\right)^{2}\left(\frac{D_1}{D_0}\right)^{2}$$

for the same impeller, $D_0 = D_1$

$$\mathbf{\frac{H_1}{H_0} = \left(\frac{N_1}{N_0}\right)^{2}}$$




PUMP (Affiity) LAWS

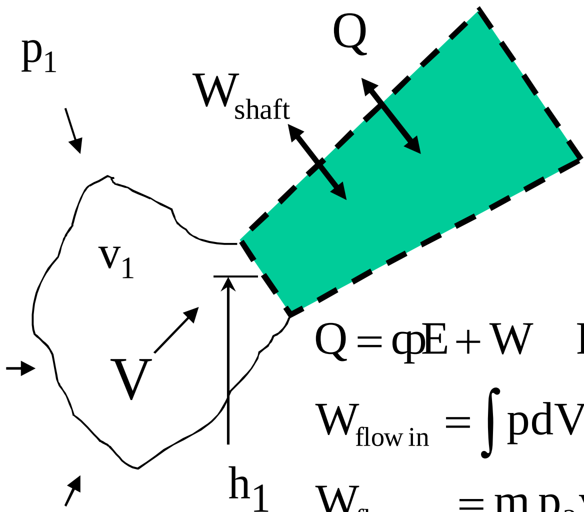
$$Q = Q_O\left(\frac{N}{N_O}\right)$$

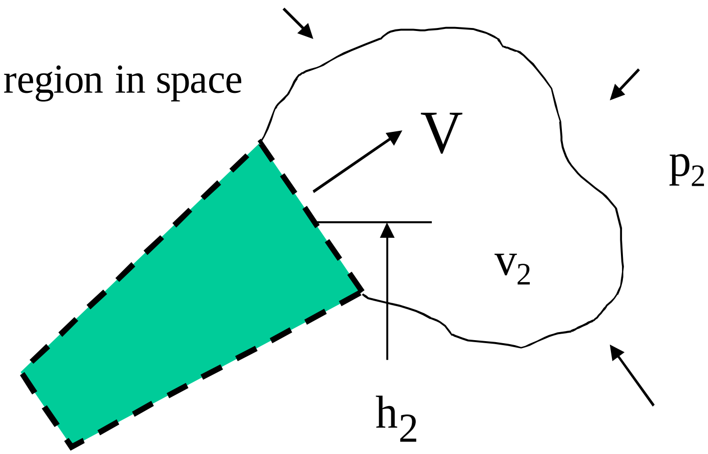
$$H = H_O\left(\frac{N}{N_O}\right)^2$$

$$HP = HP_O\left(\frac{N}{N_O}\right)^3$$

# Steady Flow Energy Equation

Open, steady flow thermodynamic system - a region in space




$$Q = \varphi E + W \quad \text{First Law}$$

$$W_{\text{flow in}} = \int p\,dV = p_1\left(V_{1\text{ initial}} - V_{1\text{ final}}\right) = p_1 V_1 = m\,p_1 v_1$$

$$W_{\text{flow out}} = m\,p_2 v_2$$

$$W = W_{shaft} + W_{\text{flow in}} + W_{\text{flow out}} = W_{shaft} + m\,p_1 v_1 - m\,p_2 v_2$$

$$E = U(T) + KE + PE = U(T) + \frac{V^2}{2} + h$$

$$Q = m(u_1 + p_1 v_1 + \frac{V^2}{2} + h_1) - m(u_2 + p_2 v_2 + \frac{V^2}{2} + h_2) + W_{shaft}$$

$$Q = m \times \Delta(u + pv + \frac{V^2}{2} + h) + W_{shaft}$$

$$KE_{ENGLISH} = \frac{(ft/sec)^2}{2 \times 32.2} = \frac{ft - lb}{lb} \qquad KE_{METRIC} = \frac{(m/sec)^2}{2 \times 1000 \frac{m^2/sec^2}{kJ/kg}} = \frac{kJ}{kg}$$

FIRST LAW BALANCE

$$Q = \mathrm{qp}\, m \times (U + pv + KE + PE) + W$$

adiabatic, T = constant

$$0 = m \times \Delta\left(0 + pv + \frac{V^2}{2g} + z\right) + W$$

$$\frac{p_1}{\rho_1} + \frac{V_1^2}{2g} + z_1 = \frac{p_2}{\rho_2} + \frac{V_2^2}{2g} + z_2 + w + l_f \quad (10-1a)$$

$$\frac{\mathrm{lb/ft^2}}{\mathrm{lb/ft^3}} + \frac{\mathrm{ft^2}}{\mathrm{ft/sec^2}} + \mathrm{ft} = \text{ft liquid pumped}$$

BERNOULLI'S EQUATION

1D, constant density, without friction

$$\frac{p}{\rho} + \frac{V^2}{2g} + gz = \text{constant}$$

MASS BALANCE

$$m = \rho AV = \frac{\mathrm{lb}}{\mathrm{ft^3}} \times \mathrm{ft^2} \times \frac{\mathrm{ft}}{\mathrm{sec}} = \frac{\mathrm{lb}}{\mathrm{sec}}$$

HEAD LOSS

Reynolds Number, $R_e = \dfrac{\rho VD}{\varepsilon} \quad (10-10)$

$$l_f = f \times \frac{L}{D} \times \frac{V^2}{2g} = \frac{\mathrm{ft}}{\mathrm{ft}} \times \frac{\frac{\mathrm{ft^2}}{\mathrm{sec^2}}}{\frac{\mathrm{ft}}{\mathrm{sec^2}}} = \text{ft of flowing fluid} \quad (10-6)$$

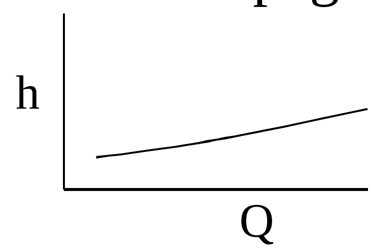
# NET POSITIVE SUCTION HEAD

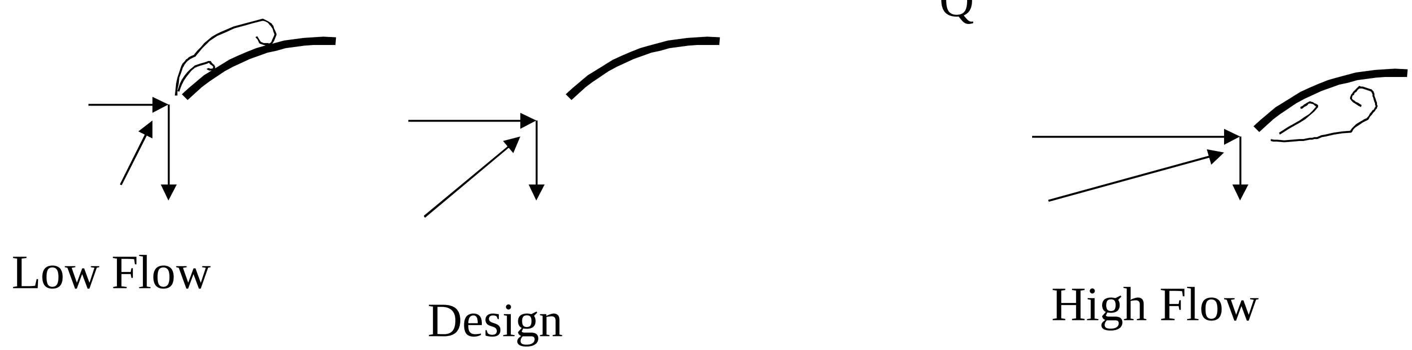
$$\text{Barometric Pressure} = \text{NPSH} + H_{\text{suction}} + \text{velocity pressure} + \text{vapor head}$$

$$\text{NPSH Avaliable} \quad = \frac{P_s}{\gamma} + \frac{V^2}{2g} - \frac{P_v}{\gamma} \qquad (10-21a)$$

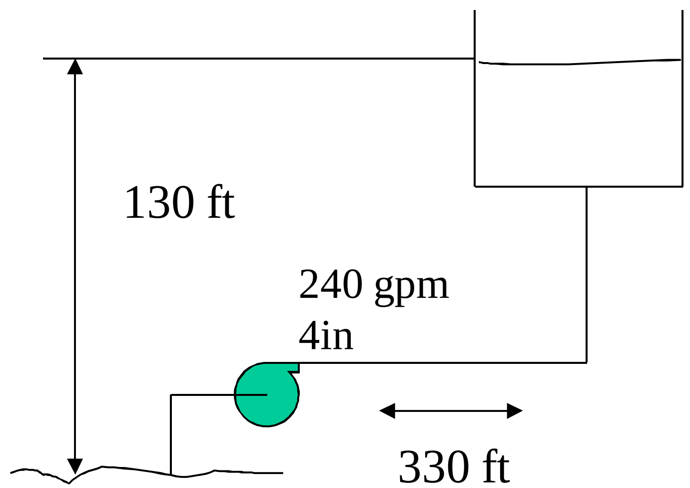
$$\text{NPSHA} = \underset{\text{at impeller suction}}{\text{absolute pressure}} - \underset{\text{of flowing fluid}}{\text{vapor pressure}}$$

NPSH Required - Pressure in excess of vapor pressure required by a pump to avoid cavitation. page 312.



**10-1.** The system shown transfers water to the tank at a rate of 240 gpm (0.015 $m^3/s$) through standard commercial steel 4 in. pipe. The total equivalent length of the pipe is 330 ft (100 m). The increase in elevation is 130 ft (40 m). Compute (a) the work done on the water and (b) the power delivered to the water, and (c) sketch the system characteristic.



# 10-1

assume $60^{o}$ F water

$$\varepsilon = 2.713\frac{lb_m}{ft\ hr},\ Ɉ = 62.37\frac{lb}{ft^3}\ \ \text{page 586 Table A} - 1a$$

$$з = \frac{\varepsilon}{Ɉ} = \frac{lb_m}{ft\ hr}\times\frac{1}{3600\ sec/hr}\times\frac{ft^3}{lb_m} = \frac{ft^2}{sec}$$

$$m = \frac{240\ gpm\times .1337 ft^3/gpm\times 62.37\ lb/ft^3}{60\ sec/hr} = 33.36\ lb/sec$$

$$A = \frac{´D}{4} = \frac{3.1416}{4}\times\left(\frac{4.026}{12}\right)^2 = .0884\ ft^2$$

$$V = \frac{Q}{A} = \frac{240\ gpm\times .1337\ ft^3/gpm}{60\ sec/hr\times .0884\ ft^2} = 6.05\ ft/sec$$

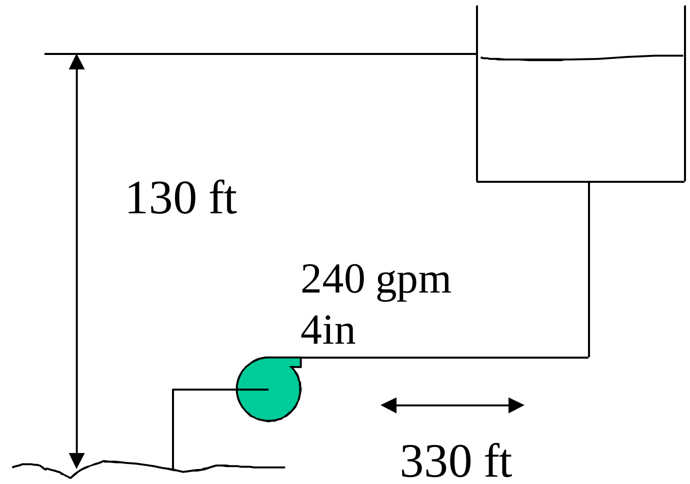
$$R_e = \frac{Ɉ VD}{\varepsilon} = \frac{62.37\ lb/ft^3\times 6.05\ ft/sec\times\left(\frac{4.026}{12}\right)}{2.713\ lb_m/ft\ hr\times 3066\ sec/hr}$$

$$R_e = 167{,}987$$

$$\frac{Ů}{D} = .00045\quad \text{Fig } 10-2$$

$$@\ R_e \text{and} \frac{Ů}{D},\quad f = .019\quad \text{Figure } 10-1$$

$$l_f = f\frac{L}{D}\left(\frac{V^2}{2g}\right) = .19\times\left(\frac{330ft}{4.026/12}\right)\times\frac{6.05^2}{2\times 32.2} = 10.62\ \ ft$$



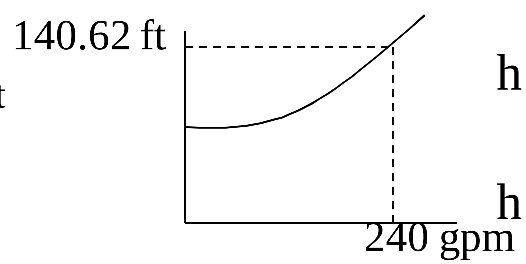

$$\frac{p_1}{Ɉ_1} + \frac{V_1^2}{2g_c} + z_1\frac{g}{g_c} = \frac{p_2}{Ɉ_2} + \frac{V_2^2}{2g_c} + z_2\frac{g}{g_c} + W + \frac{g}{g_c}l_f$$

$$W = m\times h = m\times(z_2 - z_1 + l_f)$$

$$W = 33.36\ lb(130\ ft + 10.62\ ft) = 4692\ ftlb/sec$$

$$W = \frac{4692\ ftlb/sec}{550\ ft\ lb/\ sec/\ HP} = 8.529\ HP$$

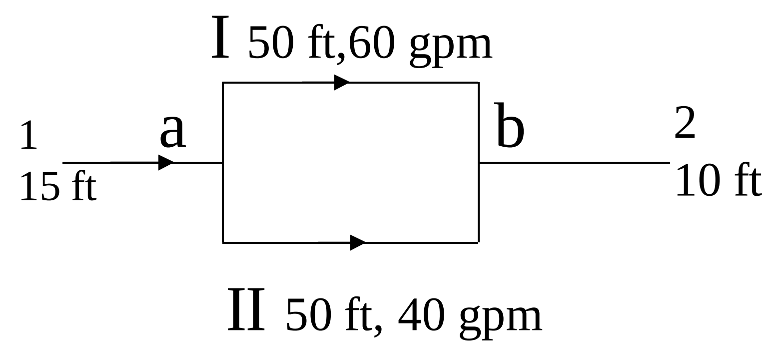
$$W = 8.529\ HP\times .7457\ KW/HP = 6.36\ KW$$




$$h = 130 + \left(\frac{h_o}{Q_o^2}\right)Q^2$$

$$h = 130 + .0001844\ Q^2$$

. Consider the piping system shown  Sketch the characteristics for each separate part of the system, and combine them to obtain the characteristic for the complete system.

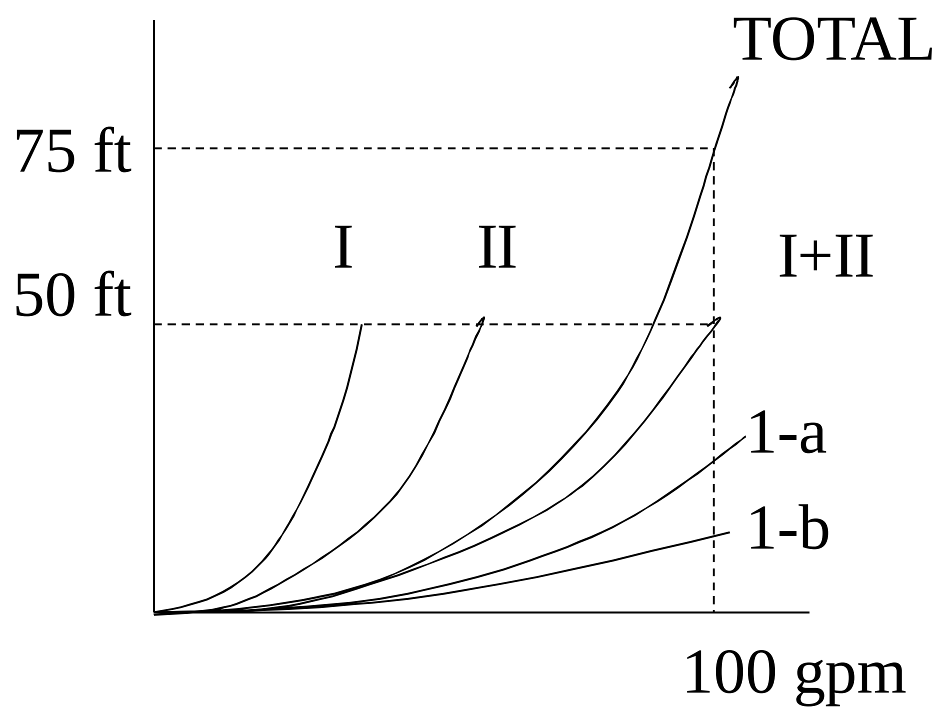



| Point | $h_l$ | GPM | |
|---|---|---|---|
| | | | $h=\left(\frac{h_o}{Q_o^2}\right)Q^2$ |
| 1 – a | 15 | 100 | $h=\left(\frac{15}{100^2}\right)Q^2$ |
| a – b I | 50 | 60 | $h=\left(\frac{50}{60^2}\right)Q^2$ |
| a – b II | 50 | 40 | $h=\left(\frac{50}{40^2}\right)Q^2$ |
| b – 2 | 10 | 100 | $h=\left(\frac{10}{100^2}\right)Q^2$ |

$$h=\sum h$$

$$h=\left[\left(\frac{15}{100^2}\right)+\left(\frac{50}{100^2}\right)+\left(\frac{10}{100^2}\right)\right]Q^2$$

$$h_{total}=.0075Q^2$$



First Law Open Systems, Steady Flow Enegy Equation

<u>10.2</u>

$$Q = \Sigma m(u + pv + ke + pe) + W$$

$$Q = 0, \ \ ke \approx 0, \ \ v = 1/\rho$$

$$p_2 + \gamma Z_2 = p_1 + \gamma Z_1 + \gamma W_p - \gamma l_f$$

$$p_2 = p_1 + \gamma W_p = (14.7 + 10) + \frac{62.4\,\text{lb/ft}^3}{144\,\text{in}^2/\text{ft}^2} \times 80\,\frac{\text{ft lbf}}{\text{lbm}}$$

$$p_2 = 27.7\,\text{psia} + .4333\,\frac{\text{psi}}{\text{ft}} \times 80\,\text{ft}$$

$$p_2 = 59.37\,\text{psia}, \ 44.6\,\text{psig}$$

$$p_3 = p_2 - \gamma(z_3 - z_2) - l_{f2-3}$$

$$p_3 = 59.37 - .433 \times 50 - .433 \times 20$$

$$p_3 = 29.06\,\text{psia}, \ 14.36\,\text{psig}$$

$$p_4 = p_3 + \gamma(z_3 - z_4) - l_{f3-4}$$

$$p_4 = 29.06 + .433 \times 25 - .433 \times 15$$

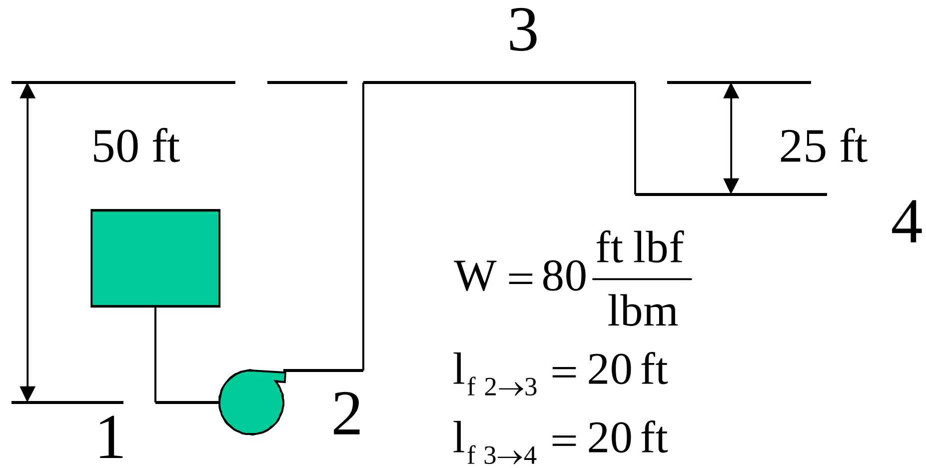
$$p_4 = 33.39\,\text{psia}, \ 18.69\,\text{psig}$$

Head at 0 flow

$$H = \frac{27.7\,\text{psia}}{.433\,\text{psi/ft}} + 25\text{ft} = 23.1\text{ft} + 25\text{ft} = 48.1\text{ft}$$

Head at 100 gpm flow

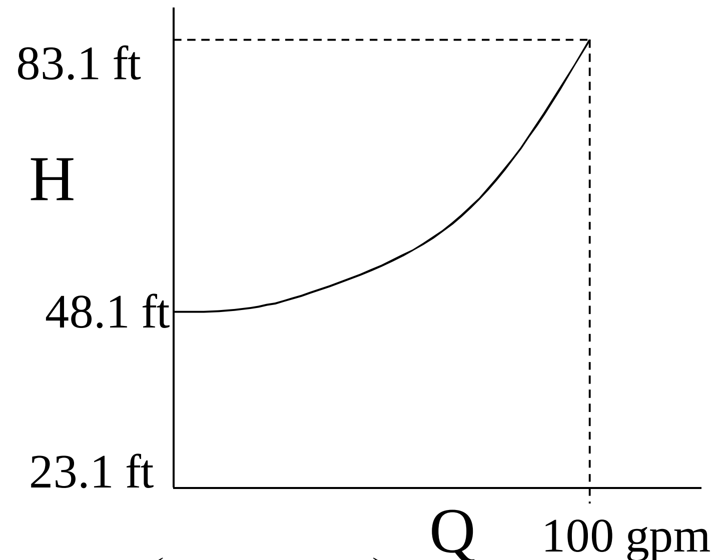
$$H = 23.1 + 25 + 20 + 15 = 83.1\,\text{ft}$$




$$W = 80\,\frac{\text{ft lbf}}{\text{lbm}}$$

$$l_{f\,2\to3} = 20\,\text{ft}$$

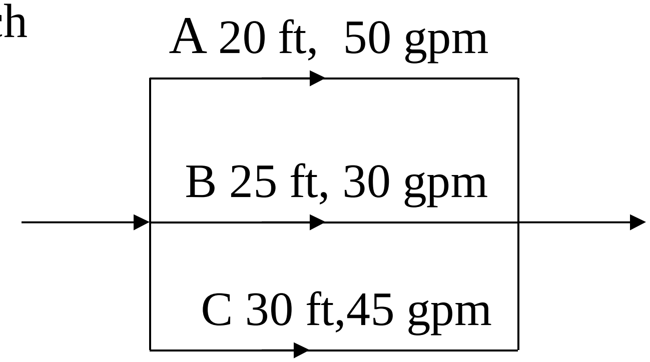
$$l_{f\,3\to4} = 20\,\text{ft}$$




$$H = 48.1 + \left(\frac{83.1 - 48.1}{100^2}\right) Q^2$$

$$H = 48.1 + .0035\,Q^2$$

Construct the head flow characteristics for each flow path and the over all characteristic.




$H = c \times Q^2$

$\quad H \quad Q$

$A \quad 20 \quad 50 \quad H = \left(\frac{20}{50^2}\right)Q^2 \quad H = .008Q^2 \qquad Q = \left(\frac{H}{.008}\right)^{.5}$

$A \quad 25 \quad 30 \quad H = \left(\frac{25}{30^2}\right)Q^2 \quad H = .0278Q^2 \qquad Q = \left(\frac{H}{.0278}\right)^{.5}$

$A \quad 30 \quad 45 \quad H = \left(\frac{30}{45^2}\right)Q^2 \quad H = .01481Q^2 \quad Q = \left(\frac{H}{.01481}\right)^{.5}$

$$Q = H^{\frac{1}{2}}\left(\left(\frac{1}{.008}\right)^{\frac{1}{2}} + \left(\frac{1}{.0278}\right)^{\frac{1}{2}} + \left(\frac{1}{.01481}\right)^{\frac{1}{2}}\right) = 25.397H^{\frac{1}{2}}$$

b)

$$H = \left(\frac{100}{25.397}\right)^2 = 15.5$$

$$Q_A = \left(\frac{15.5}{.008}\right)^{\frac{1}{2}} = 44.\text{gpm}$$

$$Q_B = \left(\frac{15.5}{.0278}\right)^{\frac{1}{2}} = 23.6\text{gpm}$$

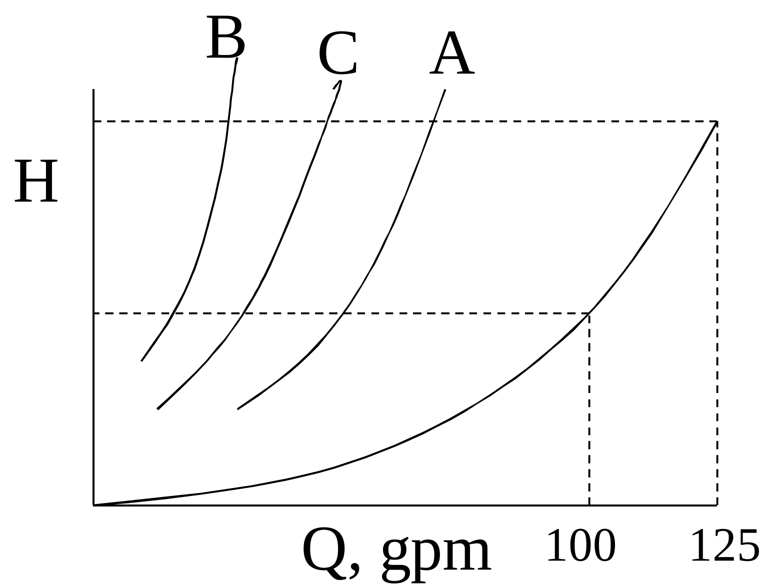
$$Q_A = \left(\frac{15.5}{.01481}\right)^{\frac{1}{2}} = 32.4\text{gpm}$$

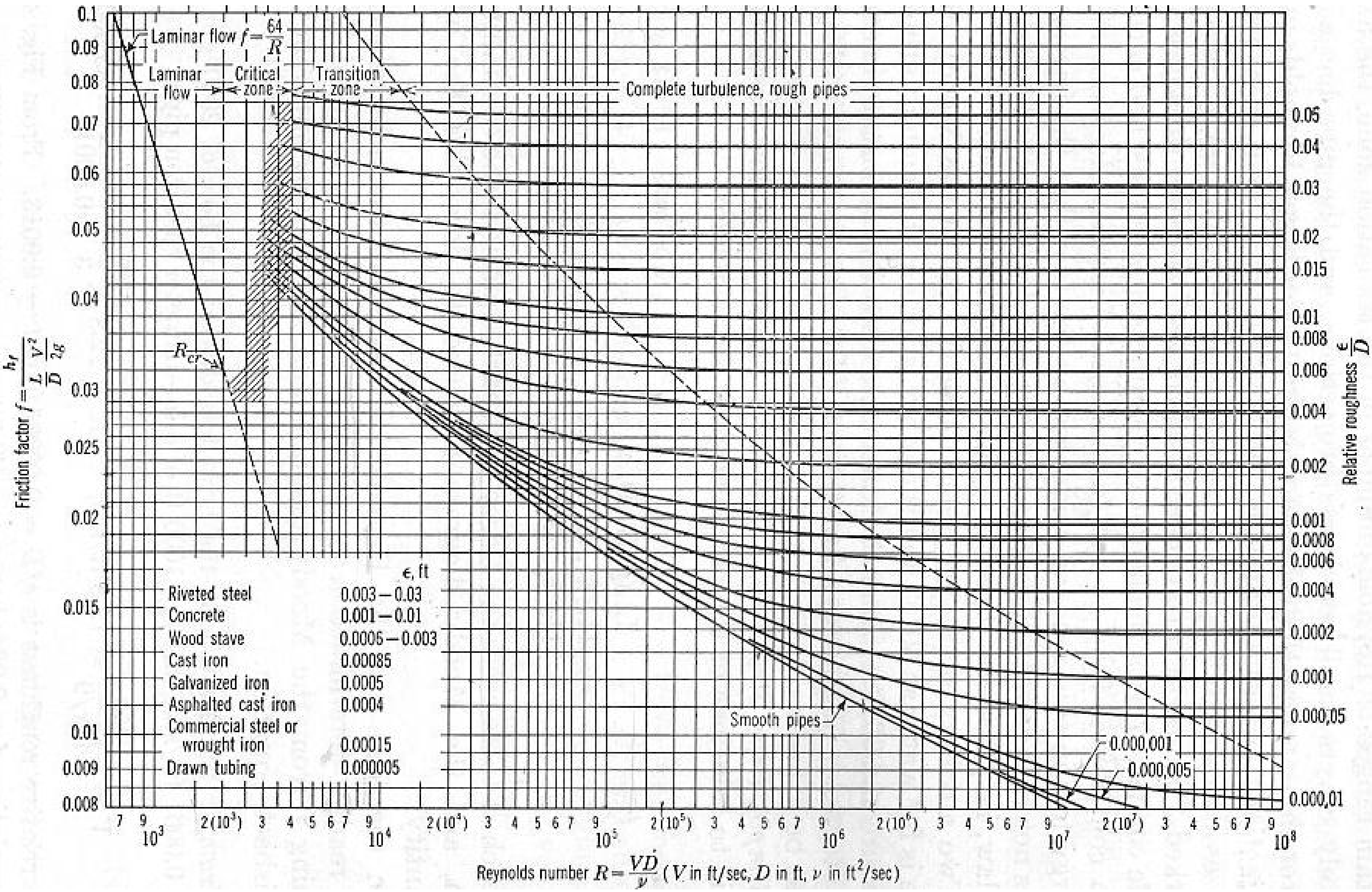
c) $H = \left(\frac{125}{25.397}\right)^2 = 24.22$

d) $Q_A = \left(\frac{24.22}{.008}\right)^{\frac{1}{2}} = 55.\text{gpm}$

$$Q_B = \left(\frac{24.22}{.0278}\right)^{\frac{1}{2}} = 29.5\text{gpm}$$

$$Q_C = \left(\frac{24.22}{.01481}\right)^{\frac{1}{2}} = 40.4\text{gpm}$$





Laminar flow $f = \frac{64}{R}$
Laminar flow
Critical zone
Transition zone
Complete turbulence, rough pipes
$R_{cr}$
Friction factor $f = \frac{h_f}{\frac{L}{D}\frac{V^2}{2g}}$
Relative roughness $\frac{\epsilon}{D}$
Smooth pipes
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.025
0.02
0.015
0.01
0.009
0.008
0.05
0.04
0.03
0.02
0.015
0.01
0.008
0.006
0.004
0.002
0.001
0.0008
0.0006
0.0004
0.0002
0.0001
0.000,05
0.000,01
0.000,001
0.000,005
ϵ, ft
Riveted steel 0.003 – 0.03
Concrete 0.001 – 0.01
Wood stave 0.0005 – 0.003
Cast iron 0.00085
Galvanized iron 0.0005
Asphalted cast iron 0.0004
Commercial steel or wrought iron 0.00015
Drawn tubing 0.000005
7 9 $10^3$ 2($10^3$) 3 4 5 6 7 9 $10^4$ 2($10^4$) 3 4 5 6 7 9 $10^5$ 2($10^5$) 3 4 5 6 7 9 $10^6$ 2($10^6$) 3 4 5 6 7 9 $10^7$ 2($10^7$) 3 4 5 6 7 9 $10^8$
Reynolds number $R = \frac{VD}{\nu}$ ($V$ in ft/sec, $D$ in ft, $\nu$ in ft$^2$/sec)

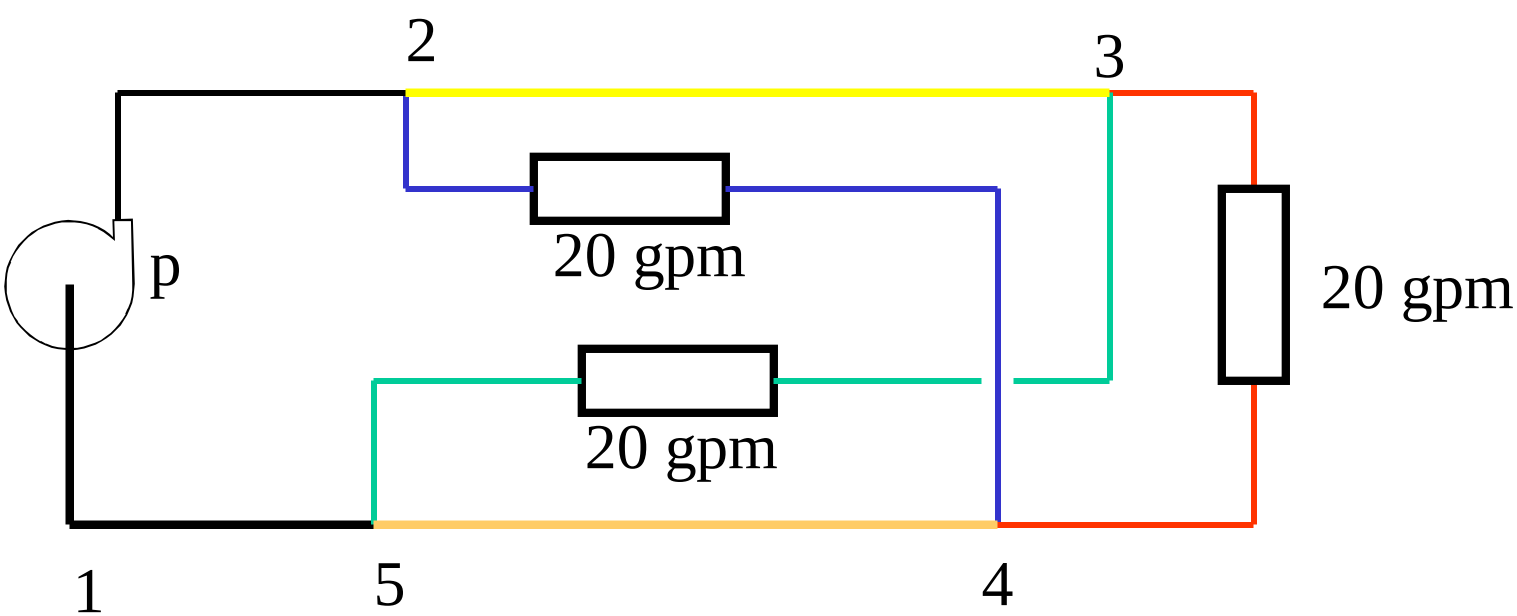
A 3-zone heating system uses hot water passing through the piping network shown. The heater increases water temperature 20 F. All pipes are copper type L.

a) What is the total head added by the pump?

b) Assuming a pump efficiency of 45%, what size electric motor should be used?

C) What is the heat flow rate into the water?

| Circuits | l eq, ft | D,in | Q, gpm |
|---|---|---|---|
| 5-1-p-2 | 40 | 2.5 | 60 |
| 2-4 | 70 | 1.5 | 20 |
| 2-3 | 55 | 2.0 | 40 |
| 3-4 | 65 | 1.5 | 20 |
| 3-5 | 60 | 1.5 | 20 |
| 4-5 | 50 | 2.0 | 40 |



heating $\Rightarrow T = 140^{o}F$, $\varepsilon = 1.129$, $\rho = 61.38 lb/ft^3$

| Section | L | D | Q | A | V | $N_{re}$ | f | $h_f$ | $Q \times H$ |
|---|---|---|---|---|---|---|---|---|---|
| | | | | $\frac{3.14 D^2}{4 \times 144}$ | $\frac{Q \times .1337}{A}$ | $\frac{VD}{\nu}$ | | | |
| $5-1-P-2$ | 40. | 2.495 | 60 | .03395 | 3.93 | $1.58 \times 10^5$ | .022 | .761 | 45.66 |
| $2-4$ | 70. | 1.527 | 20 | .01272 | 3.50 | $8.6 \times 10^5$ | .0185 | 1.936 | 38.72 |
| $2-3$ | 55. | 2.009 | 40 | .02382 | 3.74 | $1.2 \times 10^5$ | .0186 | 1.249 | 49.96 |
| $3-4$ | 65. | 1.527 | 20 | | | | | 1.798 | 35.96 |
| $3-5$ | 60. | 1.527 | 20 | | | | | 1.659 | 33.18 |
| $4-5$ | 50. | 2.009 | 40 | | | | | 1.135 | 45.40 |
| | | | | | | | | | 248.88 |

a) Head/section

$P-2-4-1 = .761 + 1.936 + 1.135 = 3.071\, ft$

$P-3-4-5-1 = .761 + 1.249 + 1.659 = 3.669\, ft$

$P-2-3-5 = .761 + 1.249 + 1.798 + 1.135 = 4.943\, ft$ maximum head

b)

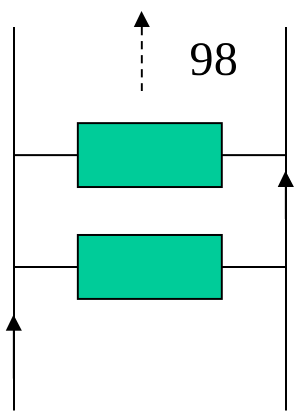
$$Power = \sum m \times H = \sum \frac{Q \times .1337 \times \rho}{60\, sec/min} \times H = \frac{.1337 \times 61.4}{60} \sum QH$$

$$Ideal\ Power = \frac{.1337 \times 61.4}{60} \times \frac{248.88 \times .7457\ KW/HP}{550\ ftlb/HP} = .0462\ KW$$

$$Actual Power = \frac{Ideal\ Power}{\eta} = \frac{.0462 HP}{.45} = .103\ KW$$

c) $$Q = m(h_2 - h_1) = \frac{60 gpm \times .1337 ft^3/gal \times 61.4(117.89 - 97.9)}{60 sec/min} = 590{,}751 BTU/hr$$

A system has 100 radiative heaters with a maximum capacity of 10,000 BTU/hr each. Circulating water enters at 200 F and returns at 180 F. The heaters are all connected in a reverse-return circuit, making all pipe runs equal. The equivalent length is 420 ft including all losses for valves, fittings and bends. The building specification requires that the piping systems be sized such that the pressure drop per equivalent foot of pipe is between .25 in and .65 in water. Curves for 3 possible pumps to supply the water to the system are given. Select the best pump for the job and determine the required pipe size for a) a 1mm BTU/ hr system and a .3 mm BTU/hr system




| | Head | | |
|---|---|---|---|
| | Pump Number | | |
| Gpm | 1 | 2 | 1 |
| 10 | 5.3 | 8.8 | 13.3 |
| 20 | 5.5 | 9.0 | 13.4 |
| 30 | 5.5 | 9.1 | 13.4 |
| 40 | 5.4 | 8.9 | 13.3 |
| 50 | 5.2 | 8.7 | 13.1 |
| 60 | 4.9 | 8.4 | 12.7 |
| 70 | 4.5 | 8.0 | 12.3 |
| 80 | 3.9 | 7.4 | 11.8 |
| 90 | 3.3 | 6.8 | 11.1 |
| 100 | 2.5 | 5.8 | 10.0 |
| 110 | 1.4 | 4.3 | 8.3 |

$$q = m \times \left(h_2 @ 200^o F - h_1 @ 180^o F\right)$$

$$1{,}000{,}000. = m(167.94 - 147.92)$$

$$m = 49{,}825. \text{ lb/hr}$$

$$Q = \frac{m}{\text{Ɉ} \times .1337 \times 60}$$

$$Q = \frac{49{,}826.}{61.13 \times .1337 \times 60} = 103.3 \text{ gpm}$$

Head Required

$$\text{max head} = 420 \text{ ft} \times .25/12 = 8.75 \text{ ft}$$

$$\text{minhead} = 420 \times .65/12 = 22.75 \text{ ft}$$

For the 1 mm BTU system

Pump3 can provide 10 ft @ 100 gpm

For the .3 mm BTU system

Pump 2 and 3 can provide the head.

For the 1 mm BTU system

– interpolate for Pump 3

to get H = 9.507 @ 103.3gpm

$$9.507 = f \frac{L}{D} \frac{V^2}{2g}$$

$$V = \frac{Q}{A} = \frac{Q \times 4}{3.14 \times D^2} = \frac{.2931}{D^2}$$

assume f = .020 and check

$$9.507 = .020 \frac{420}{D} \left(\frac{.2931}{D^2}\right)^2 \frac{1}{2g}$$

$$D = 3.115 \text{ in}$$

check f

$$V = \frac{.2931}{D^2} = 4.35 \text{ ft/sec}$$

$$N_{re} = \frac{VD}{\text{з}} = \frac{4.35 \frac{3.115}{12}}{.362 \times 10^{-5}} = 3.12 \times 10^5$$

$$\text{Ů} = .0002, \quad \frac{\text{Ů}}{D} = .008, \quad f = .020$$

For the .3mm BTU system

For Pump 2 H = 9.0 ft at 30.8gpm

$$9.00 = f\,\frac{L}{D}\,\frac{V^2}{2\,g}$$

$$V = \frac{Q}{A} = \frac{Q \times 4}{3.14 \times D^2} = \frac{.08793}{D^2}$$

assume f = .022 and check

$$9.00 = .022\,\frac{420}{D}\left(\frac{.08793}{D^2}\right)^2 \frac{1}{2g}$$

$$D = 1.983 \text{ in}$$

check f

$$V = \frac{.08793}{D^2} = 3.22 \text{ ft/sec}$$

$$N_{re} = \frac{VD}{з} = \frac{3.22\,\frac{1.983}{12}}{.362 \times 10^{-5}} = 1.46 \times 10^5$$

$$Ů = .0002, \quad \frac{Ů}{D} = .00128, \quad f = .022$$

For Pump 3 H = 13.408 ft at 30.8 gpm

$$13.408 = f\,\frac{L}{D}\,\frac{V^2}{2\,g}$$

$$V = \frac{Q}{A} = \frac{Q \times 4}{3.14 \times D^2} = \frac{.08793}{D^2}$$

assume f = .022 and check

$$13.408 = .022\,\frac{420}{D}\left(\frac{.08793}{D^2}\right)^2 \frac{1}{2g}$$

$$D = 1.826 \text{ in}$$

check f

$$V = \frac{.08793}{D^2} = 3.80 \text{ ft/sec}$$

$$N_{re} = \frac{VD}{з} = \frac{3.80\,\frac{1.826}{12}}{.362 \times 10^{-5}} = 1.6 \times 10^5$$

$$Ů = .0002, \quad \frac{Ů}{D} = .0013, \quad f = .022$$

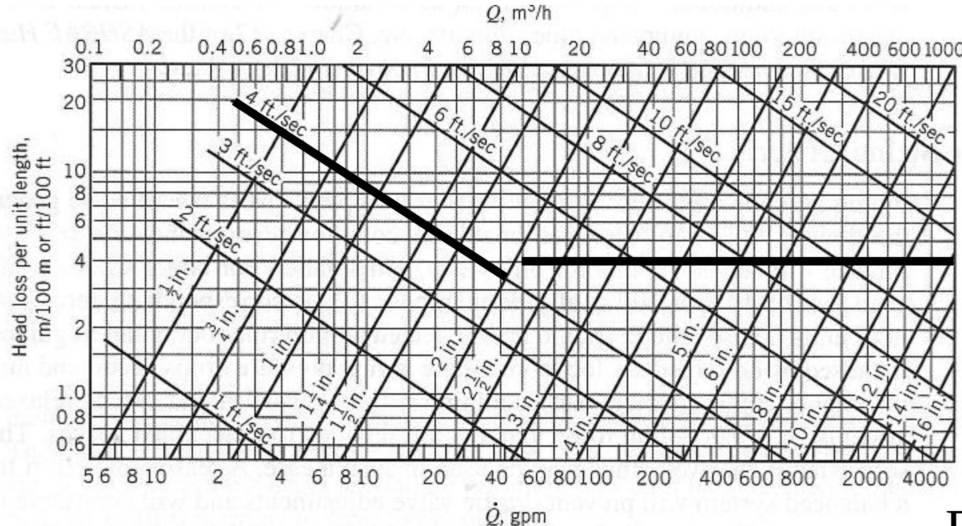



**Figure 10-20** Friction loss due to flow of water in commercial steel pipe (schedule 40). (Reprinted by permission from *ASHRAE Handbook, Fundamentals Volume*, 1989.)

DESIGN CRITERIA

4 ft/sec less than 2 in diameter

4 ft/100 ft greater than 2 in diameter

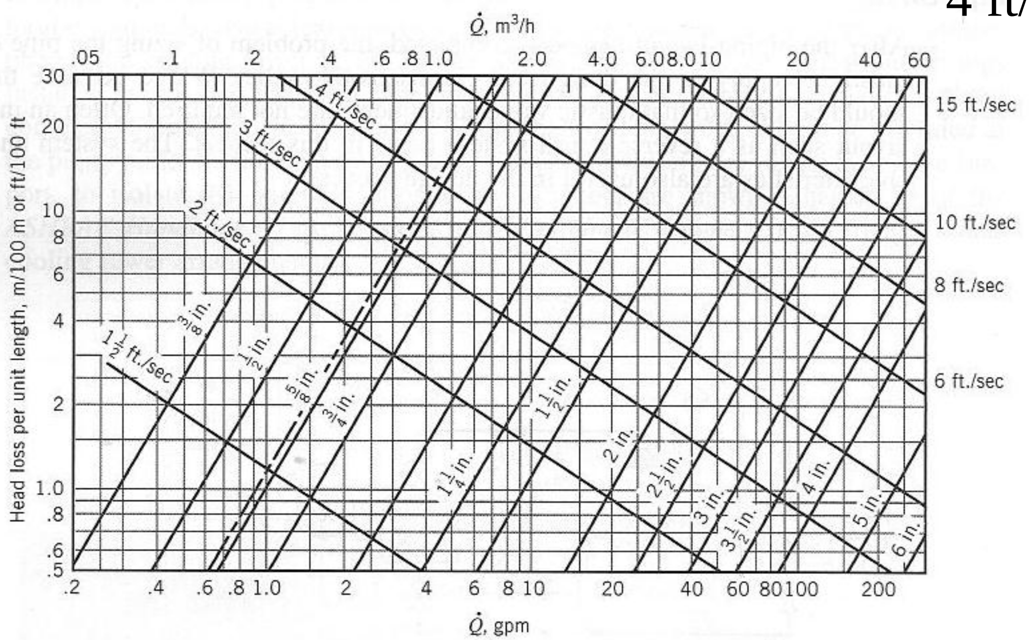



**Figure 10-21** Friction loss due to flow of water in type L copper tubing. (Reprinted by permission from *ASHRAE Handbook, Fundamentals Volume*, 1989.)

**HEAD LOSS**

$$l_f = f_t \frac{L}{D}\left(\frac{V^2}{2g}\right) = \frac{ft}{ft} \times \frac{\frac{ft^2}{sec^2}}{\frac{ft}{sec^2}} = ft$$

$$l_{eq} = K\left(\frac{V^2}{2g}\right)$$

$$K = f_t \times \left(\frac{L}{D}\right), \text{Resistance Coefficient}$$

Example, 3 in Globe Valve

$f_t$ Page 323 for pipe size

Page 321 $L/D = 340$

Page 323 fo r3in pipe $f_t = .018$

$K, \text{Resistance Coefficient} = 340 \times .018 = 6.1$

Also from Figure 10 – 24 b

Equivalent length of 3in pipe = 86ft

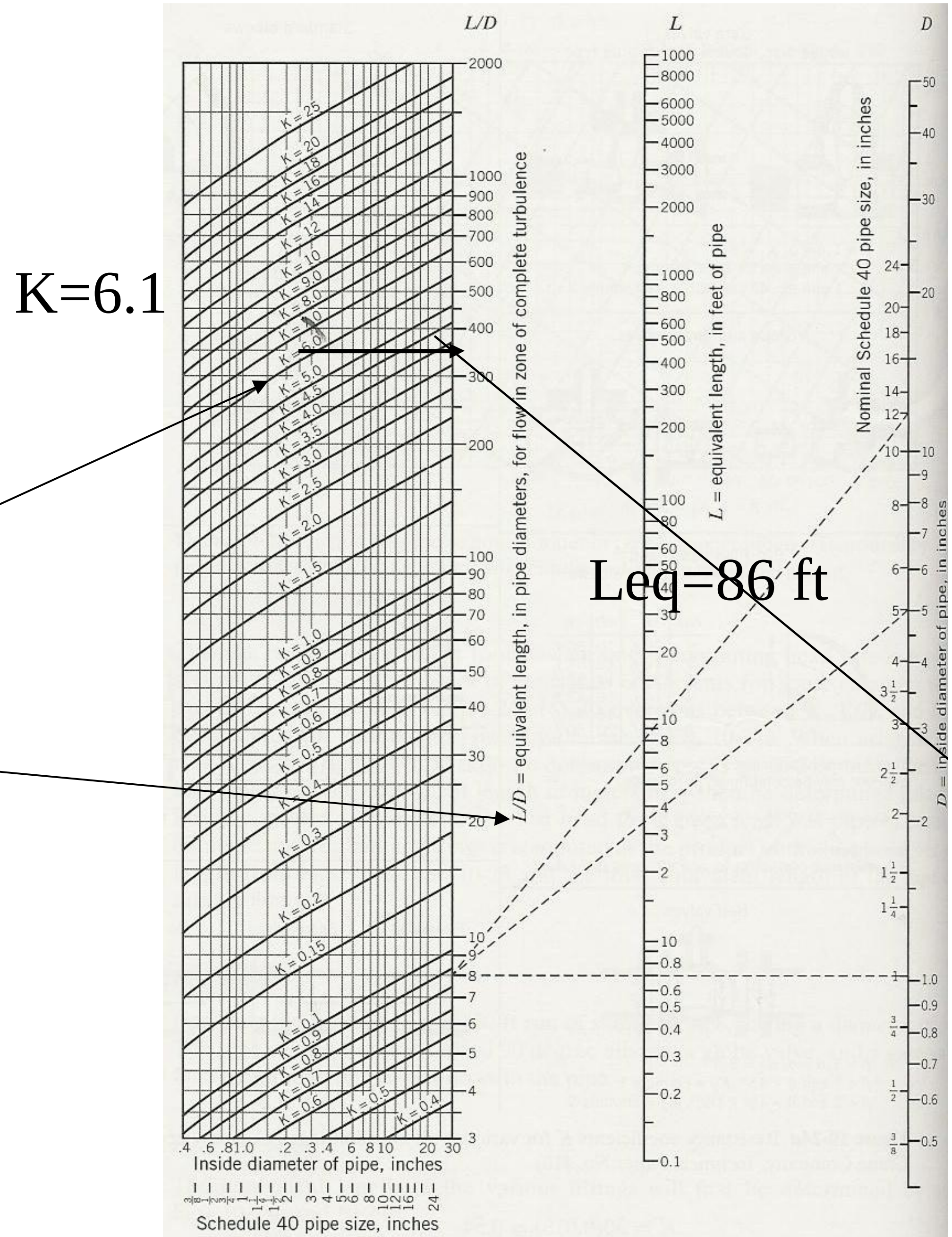



**Figure 10-24*b*** Equivalent lengths *L* and *L/D* and resistance coefficient *K*. (Courtesy of the Crane Company, Technical Paper No. 410)

Size the piping for the layout shown and specify the pump requirements. Assume that all the turns and fittings are as snown on the diagram. The pipe is commercial steel. Table 10-7 gives the required data.

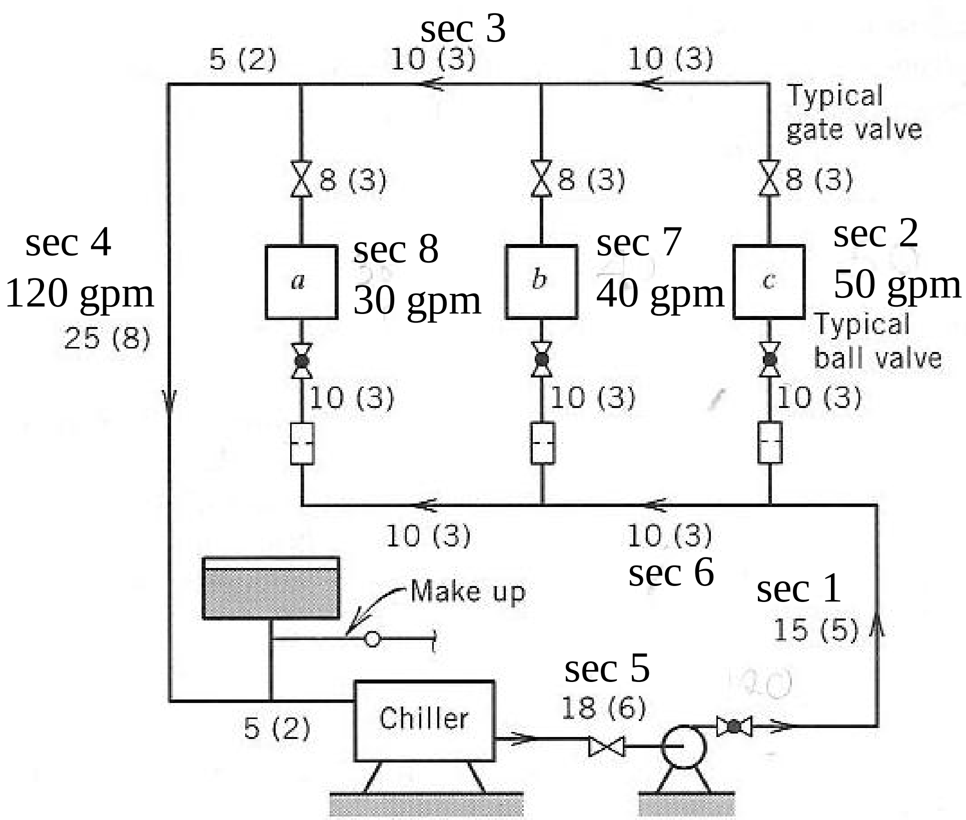
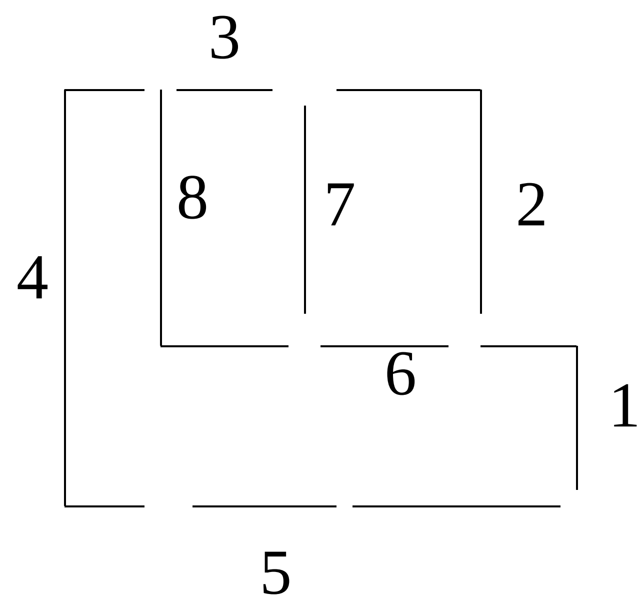



**Table 10-7** Data for Problem 10-23

| Unit | Flow Rate, gpm | Head Loss, ft | |
|---|---|---|---|
| | | Coil | Orifice |
| *a* | 30 | 15 | 6 |
| *b* | 40 | 12 | 6 |
| *c* | 50 | 10 | 6 |
| Chiller | 120 | 20 | — |



# PIPE FITTINGS

## Gate Valve

| | | | |
|---|---|---|---|
| D, nominal | 2 | 2.5 | 3 |
| K, Fig 10-22a | 8 | 8 | 8 |
| f t, friction factor | 0.019 | 0.018 | 0.018 |
| K | 0.152 | 0.144 | 0.144 |
| L eq, Fig 10-22b, ft | 1.4 | 1.8 | 2 |

## Elbow

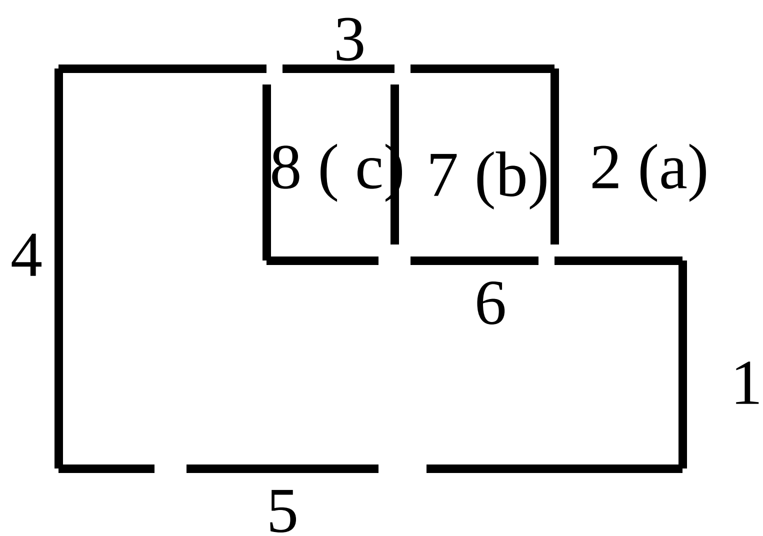
| | | | |
|---|---|---|---|
| D, nominal | 2 | 2.5 | 3 |
| K, Fig 10-22a | 30 | 30 | 30 |
| f t, friction factor | 0.019 | 0.018 | 0.018 |
| K | 0.57 | 0.54 | 0.54 |

# Problem 10-23

| Section | 1 | 2 (a) | 3 | 4 | 5 | 6 | 7 (b) | 8( c) |
|---|---|---|---|---|---|---|---|---|
| Q, gpm | 120 | 50 | 90 | 120 | 120 | 70 | 40 | 30 |
| Criteria | 4ft/100 | 4 ft/sec | 4 ft/sec | 4 ft/100 | 4 ft/100 | 4 ft/sec | 4 ft/sec | 4 ft/sec |
| D nominal, in | 3.00 | 2.00 | 2.50 | 3.00 | 3.00 | 2.50 | 2.00 | 2.00 |
| loss, l f, ft/100ft | 3.27 | 1.75 | 4.90 | 3.27 | 3.27 | 3.16 | 2.88 | 1.74 |
| Pipe Length | 15.00 | 28.00 | 10.00 | 35.00 | 18.00 | 10.00 | 18.00 | 28.00 |
| Equivalent Length | | | | | | | | |
| Elbows | 16.00 | 5.00 | | 16.00 | | | | 5.00 |
| Gate Valve | | 1.40 | | | 2.00 | | 1.40 | 1.40 |
| Through Tee | | 4.00 | 8.00 | 5.30 | | 8.60 | | 3.50 |
| Branch Tee | | 12.00 | | | | | 24.00 | 12.00 |
| Total L eq | 31.00 | 50.40 | 18.00 | 56.30 | 20.00 | 18.60 | 43.40 | 49.90 |
| loss, l f | 1.01 | 0.88 | 0.88 | 1.84 | 0.65 | 0.59 | 1.25 | 0.87 |
| Coil loss | | 10.00 | | | | | 12.00 | 15.00 |
| Orrifice Loss | | 6.00 | | | | | 6.00 | 6.00 |
| Cooler | | | | | 20.00 | | | |
| Total loss | 1.01 | 16.88 | 0.88 | 1.84 | 20.65 | 0.59 | 19.25 | 21.87 |

Sections 2 (a), 7 (b) and 8( C) arein parallel. use the highest head loss, section 8 ( C)

Total Head required= 1+3+4+5+6+8 46.84297



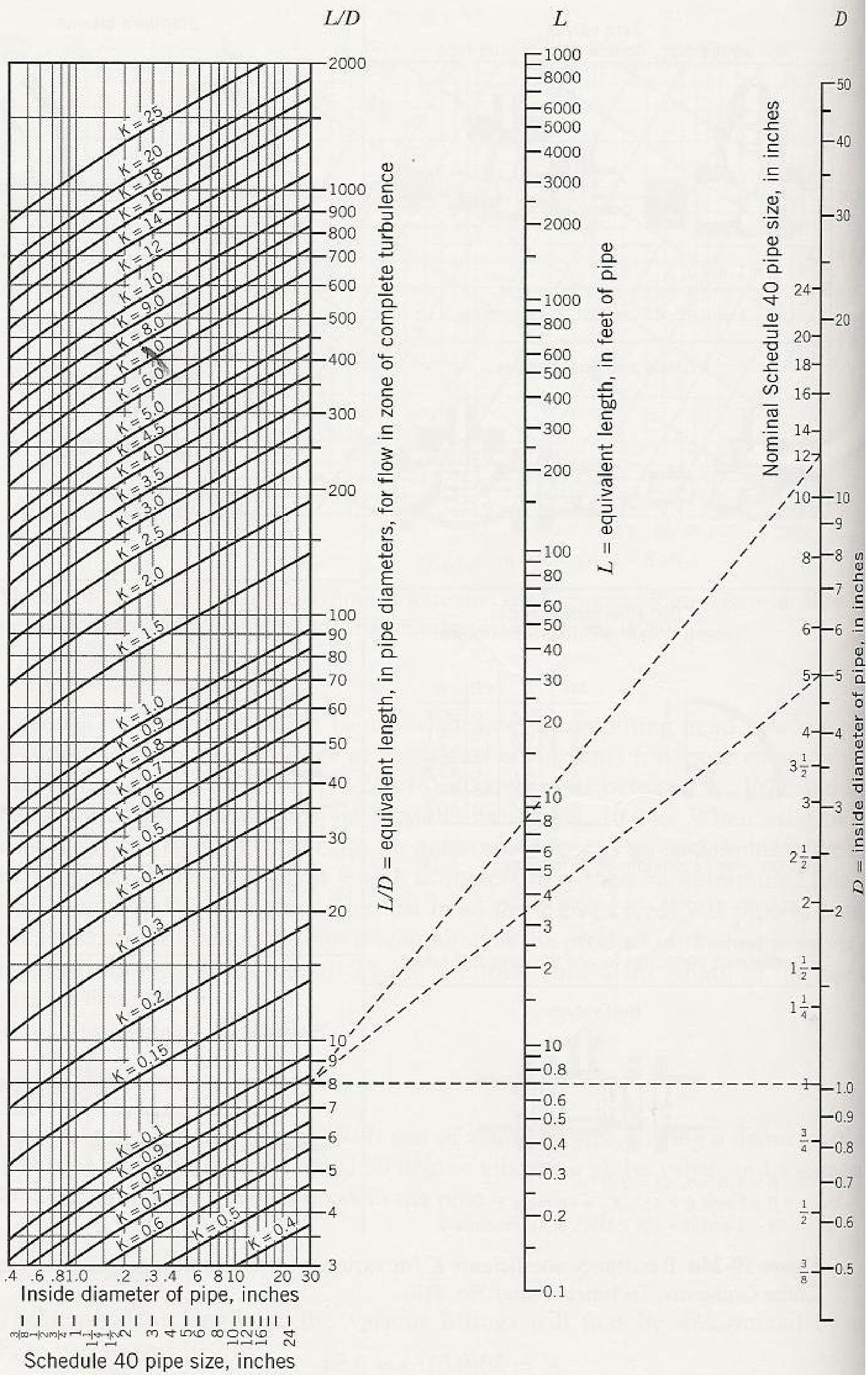



**Figure 10-24*b*** Equivalent lengths *L* and *L/D* and resistance coefficient *K*. (Courtesy of the Crane Company, Technical Paper No. 410)

# EXPANSION TANK

$$V_T = \frac{V_w\left[\left(\frac{v_2}{v_1} - 1\right) - 3\alpha\,\Delta t\right]}{\frac{P_a}{P_1} - \frac{P_a}{P_2}} \qquad (10\text{-}29)$$

*where:*

$V_T$ = expansion tank volume, $ft^3$ or $m^3$
$V_w$ = volume of water in the system, $ft^3$ or $m^3$
$P_a$ = local barometric pressure, psia or kPa
$P_1$ = pressure at lower temperature, $t_1$ (regulated system pressure), psia or kPa
$P_2$ = pressure at higher temperature, $t_2$ (some maximum acceptable pressure), psia or kPa
$t_1$ = lower temperature (initial fill temperature for hot water system or operating temperature for chilled water system), F or C
$t_2$ = higher temperature (some maximum temperature for both hot and chilled water systems), F or C
$v_1$ = specific volume of water at $t_1$, $ft^3$/lbm or $m^3$/kgm
$v_2$ = specific volume of water at $t_2$, $ft^3$/lbm or $m^3$/kgm
$\alpha$ = linear coefficient of thermal expansion for the piping, $F^{-1}$ or $C^{-1}$: $6.5 \times 10^{-6}$ $F^{-1}$ ($11.7 \times 10^{-6}$ $C^{-1}$) for steel pipe, and $9.3 \times 10^{-5}$ $F^{-1}$ ($16.74 \times 10^{-6}$ $C^{-1}$) for copper pipe
$\Delta t$ = higher temperature minus the lower temperature, F or C

If the initial air charge in the tank is not compressed from atmospheric pressure but rather is forced into the tank at the design operating pressure, as with a bladder-type tank, and then expands or compresses isothermally, the following relation re

$$V_T = \frac{V_w\left[\left(\frac{v_2}{v_1} - 1\right) - 3\alpha\,\Delta t\right]}{1 - \frac{P_1}{P_2}}$$

$$V_T = \frac{V_w\left[\left(\frac{v_2}{v_1} - 1\right) - 3\alpha\,\Delta t\right]}{\frac{P_a}{P_1} - \frac{P_a}{P_2}} \tag{10-29}$$

$$V_T = \frac{V_w\left[\left(\frac{v_2}{v_1} - 1\right) - 3\alpha\,\Delta t\right]}{1 - \frac{P_1}{P_2}}$$

10-28

$$t_1 = 60^o F$$

$$t_2 = 220^o F$$

$$P_2 = 50 \text{ psig}$$

$$P_1 = 20 \text{ psig}$$

$$v_1 = .016053 \text{ ft}_3/\text{lb}$$

$$v_2 = .016772 \text{ ft}_3/\text{lb}$$

$$V_T = \frac{1200\left[\left(\frac{.016772}{.016035} - 1\right) - 3 \times 9.3 \times 10^{-5}(150)\right]}{\left(\frac{14.696}{36.696} - \frac{14.696}{64.696}\right)}$$

$$V_T = 9.2 \text{ gal} = 35 \text{ liters}$$