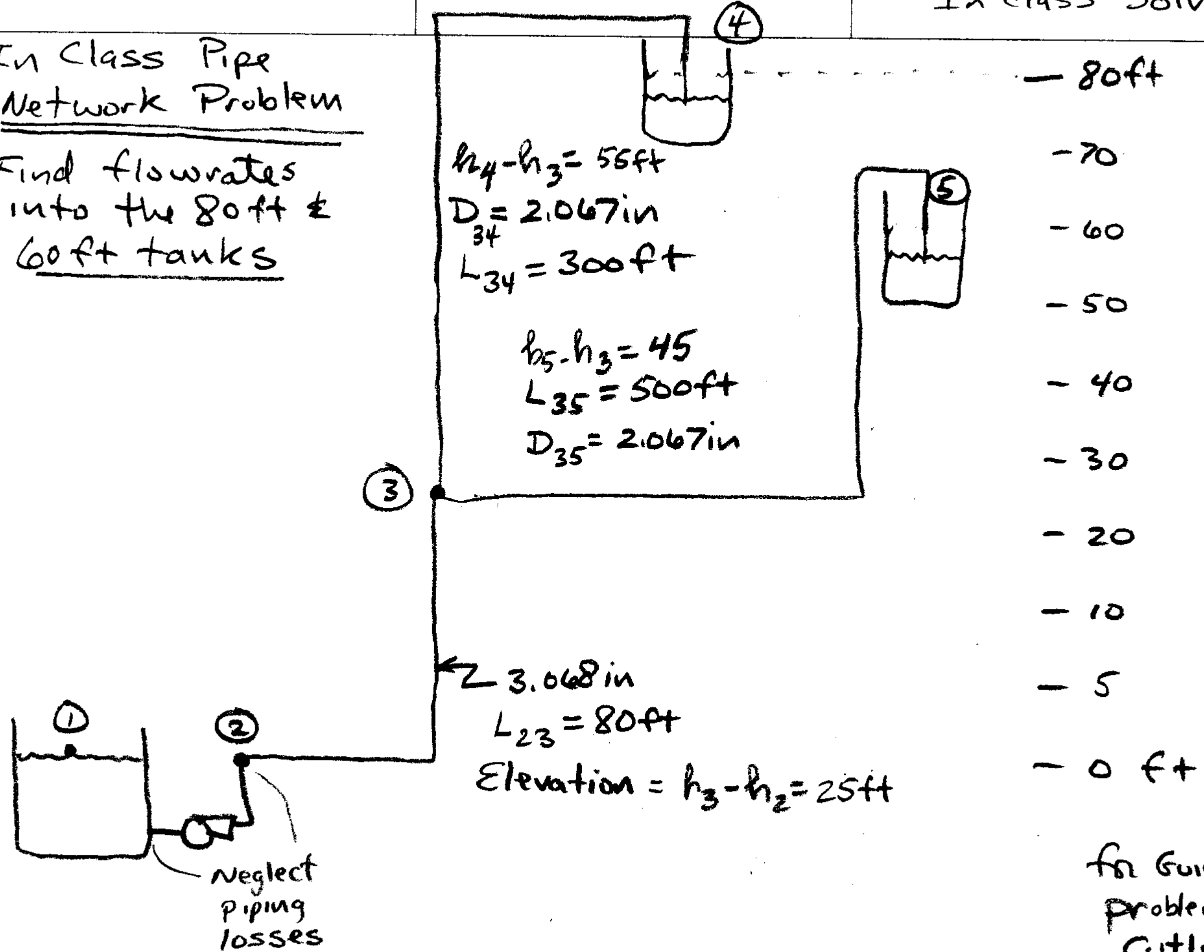
In Class Pipe Network Problem

Find flowrates into the 80ft & 60ft tanks



for Guidence problem 5.11 Cutlip p 184

(4) $\Delta P_p = \left[-72 psig + \frac{0.0042 psig}{(GPM)^2} F_1^2 \varphi^2 \right] \frac{1.01325 \times 10^5 Pa}{14.696 psig}$

$F_1 = (1gal/3.785L)\left(\frac{10^3 L}{m^3}\right)\left(\frac{60s}{min}\right)$

1-2

(overall $1 \rightarrow 4$)

$$\cancel{P_1}^{0} + \cancel{\rho g h_1}^{0} + \cancel{\tfrac{1}{2}\rho v_1^2}^{0} + \frac{\dot{W}_s}{\varphi} = P_2 + \cancel{\rho g h_2}^{0} + \tfrac{1}{2}\rho v_2^2 + \cancel{\text{losses}}^{\text{neglect}}$$

$$\frac{\dot{W}_s}{\varphi} = P_2 - P_1 + \tfrac{1}{2}\rho v_2^2 \quad \& \quad P_1 - P_2 = \Delta P_{pump} = -\frac{\dot{W}_s}{\varphi} + \tfrac{1}{2}\rho v_2^2$$

Notice that ΔP_{pump} includes the v_2^2 term

Segment 2-3

$$P_2 + \cancel{\rho g h_2}^{0} + \cancel{\tfrac{1}{2}\rho v_2^2} + \cancel{\dot{W}_s}^{0} = P_3 + \rho g h_3 + \cancel{\tfrac{1}{2}\rho v_3^2} + \text{losses}$$

(5) ΔP_{23} (Cutlip) $= P_2 - P_3 = \rho g (h_3 - h_2) + 2\rho f_{F_{23}} v_{23}^2 \frac{L_{23}}{D_{23}}$

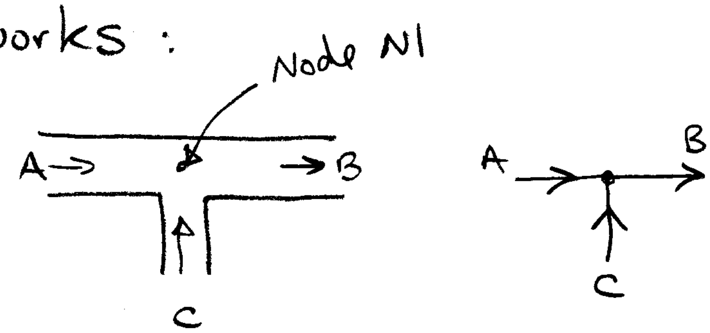
Segment 3-4

(6) $\Delta P_{34} = P_3 - P_4 = \rho g (h_4 - h_3) + 2\rho f_{F_{34}} v_{34}^2 \frac{L_{34}}{D_{34}}$

Segment 3-5

(7) $\Delta P_{35} = P_3 - P_5 = \rho g (h_5 - h_3) + 2\rho f_{F_{35}} v_{35}^2 \frac{L_{35}}{D_{35}}$

Pipe Networks:



For each Node (intersection)

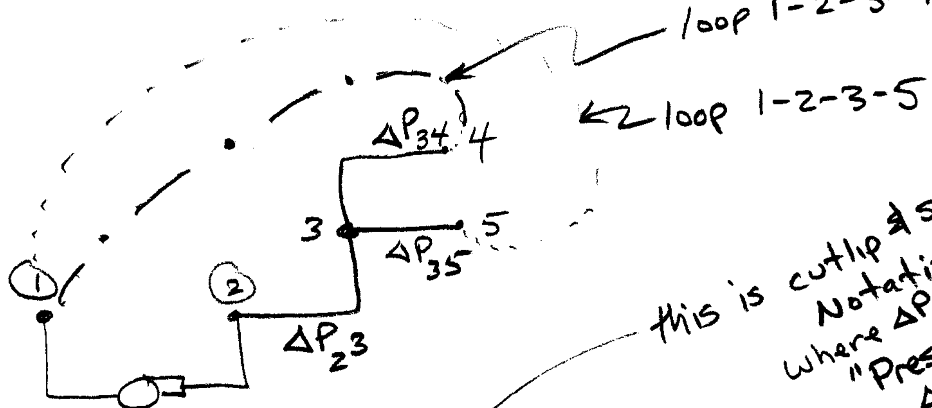
1) Pressure has one value

2) Mass balance $\dot{m}_A + \dot{m}_C = \dot{m}_B$

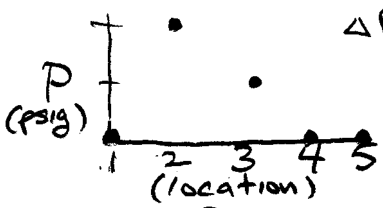
For each loop:

the net pressure drop is zero

Exampl 1



this is cutlip & schacham's Notation where ΔP equals "Pressure drop" $\Delta P_{23} = P_2 - P_3$

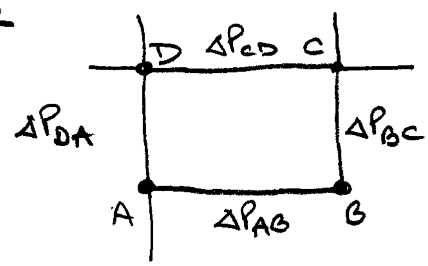


ΔP_{12}

$\Delta P_{12} = \Delta P_{23} + \Delta P_{35}$ loop of 1-2-3-5

$\Delta P_{12} = \Delta P_{23} + \Delta P_{34}$ 1-2-3-4

examp 2



Loop A-B-C-D

$0 = \Delta P_{AB} + \Delta P_{BC} + \Delta P_{CD} + \Delta P_{DA}$

Because the pressure drop starting at B and ending at B must be zero: $P_B - P_B = 0$

Now use $\varphi = \frac{\pi}{4} D^2 v$

$$\text{frictional straight pipe flow losses} = 2\rho f_F \left(\frac{4\varphi}{\pi D^2}\right)^2 \frac{L}{D}$$

$$= 2\rho f_F \frac{16\varphi^2 L}{\pi^2 D^5} = \underbrace{\frac{32\rho f_F \varphi^2 L}{\pi^2 D^5}}_{\text{in cutlip}}$$

$$= K_{ij}\varphi_{ij}^2$$

Now look at loops

$\Delta P_{ij} > 0$ if in flow direction

$P_i \quad P_j$

$i \longrightarrow j$ if $P_i > P_j$

flow direction

$\Delta P_p < 0$ if in flow direction

pump

x (1) $\quad 0 = \Delta P_p + \Delta P_{23} + \Delta P_{34}$ or $(-\Delta P_p) = \Delta P_{23} + \Delta P_{34}$

x (2) $\quad 0 = \Delta P_p + \Delta P_{23} + \Delta P_{35}$

why zero? $\quad P_1 - P_5 = 0 \quad P_1 - P_4 = 0$

Rule $\Sigma \Delta P = 0$

x (3) $\quad$ Node 3 $\quad \rho\varphi_{23} = \rho\varphi_{34} + \varphi_{35}\rho$ } mass balance

Now we have 7 equations

$$f_F = \frac{1}{16\left[\log\left(\frac{\epsilon/D}{3.7} - \frac{5.02}{Re}\log\left\{\frac{\epsilon/D}{3.7} + \frac{14.5}{Re}\right\}\right)\right]^2} \quad \text{5-48}$$

this needs to be a constant for this problem for a first Run

Steel Pipe $\quad \epsilon = 0.045\,\text{mm}$

$$Re = \frac{\rho v D}{\mu} = \frac{\rho \cancel{D}}{\mu}\frac{4\varphi}{\pi D^{\cancel{2}}}$$

variables:

$\varphi_{23} \quad \varphi_{34} \quad \varphi_{35} \quad \Delta P_p \quad \Delta P_{23} \quad \Delta P_{34} \quad \Delta P_{35}$

✓ ✓ ✓

POLYMATH Results

Flow Distribution in a Pipeline Network In-Class Problem 03-01-2001, Rev5.1.224

NLES Solution

Variable	Value	f(x)	Ini Guess
q23	0.005541	7.567E-10	0.02
q34	0.0026292	4.337E-19	0.01
q35	0.0029117	6.403E-10	0.01
e	4.5E-05		
F1	1.585E+04		
D23	0.0779272		
eltaPUMP	-2.73E+05		
mu	0.001		
rho	1000		
pi	3.1416		
Re23	9.053E+04		
D34	0.0525018		
D35	0.0525018		
Re34	6.376E+04		
fF23	0.0052335		
fF34	0.0057189		
Re35	7.061E+04		
fF35	0.0056449		
k23	1.44E+08		
k34	4.25E+09		
k35	6.992E+09		

NLES Report (safenewt)

Nonlinear equations

[1] f(q23) = k23*q23^2+1000*9.81*25*0.3048+k34*q34^2+1000*9.81*55*.3048+deltaPUMP = 0

[2] f(q34) = q23-q34-q35 = 0

[3] f(q35) = k23*q23^2+1000*9.81*25*.3048+k35*q35^2+1000*9.81*45*.3048+deltaPUMP = 0

Explicit equations

[1] e = 0.045e-3

[2] F1 = 1/3.785*1000*60

[3] D23 = 3.068*0.0254

[4] deltaPUMP = (-72+0.0042*F1^2*q23^2)*1.01325e5/14.696

[5] mu = 1e-3

[6] rho = 1000

[7] pi = 3.1416

[8] Re23 = rho/mu/D23/pi*4*q23

[9] D34 = 2.067*0.0254

[10] D35 = 2.067*0.0254

[11] Re34 = rho/mu/D34/pi*4*q34

[12] fF23 = 1/(16*(log(e/D23/3.7-5.02/Re23*log(e/D23/3.7+14.5/Re23)))^2)

[13] fF34 = 1/(16*(log(e/D34/3.7-5.02/Re34*log(e/D34/3.7+14.5/Re34)))^2)

[14] Re35 = rho/mu/D35/pi*4*q35

[15] fF35 = 1/(16*(log(e/D35/3.7-5.02/Re35*log(e/D35/3.7+14.5/Re35)))^2)

[16] k23 = 32*fF23*rho*80*.3048/(pi^2*D23^5)

[17] k34 = 32*fF34*rho*300*0.3048/(pi^2*D34^5)

[18] k35 = 32*fF35*rho*500*.3048/(pi^2*D35^5)

Comments

[5] F1 = 1/3.785*1000*60

conversion from m^3/s to GPM

Handout

Equations for Fluid Mechanics I: Exam 1

Bernoulli Equation – memorize (yeah Right!)

Bernoulli with frictional losses and with no external heater or cooler:

$$P_1 + \rho g h_1 + \frac{1}{2}\rho \upsilon_1^2 + \frac{\dot{W}_s}{Q} = P_2 + \rho g h_2 + \frac{1}{2}\rho \upsilon_2^2 + 2\rho\sum_{i=1}^{n} f_{F_i}\upsilon_i^2 \frac{L_i}{D_i} + \frac{1}{2}\rho\sum_{j=1}^{m} K_{L_j}\upsilon_j^2$$

"Mechanical Energy balance with no external heater or cooler"

$$\frac{P_1}{\rho} + g h_1 + \frac{1}{2}\upsilon_1^2 + \frac{\dot{W}_s}{\rho Q} = \frac{P_2}{\rho} + g h_2 + \frac{1}{2}\upsilon_2^2 + 2\sum_{i=1}^{n} f_{F_i}\upsilon_i^2 \frac{L_i}{D_i} + \frac{1}{2}\sum_{j=1}^{m} K_{L_j}\upsilon_j^2$$

Notice that for an open system this is really a Power per mass flowrate balance

$Q \equiv$ volumetric flowrate $[=]\ \mathrm{m^3/s}$

$\dot{W}_s \equiv$ rate of shaft work or power $[=]\ \mathrm{W} = \mathrm{J/s} = (\mathrm{kg\ m^2})/\mathrm{s^3}$

$$\eta = \frac{\dot{W}_s}{\text{Brake horsepower (bhp)}}$$

The following are comments that will not appear on the exam:

Comments Notice that in all of the above equations what is commonly referred to as "shaft work" is actually rate of shaft work or power and has units of Watts or horsepower.

Definitions:

Brake horsepower or abbreviated as bhp: Is the power applied to the shaft of the pump impeller. See page 457 in Young et al.

A second efficiency term is required to account for the energy lost in the motor or driver of the pump impeller. In chemical engineering equipment notation a pump motor is referred to as a driver.