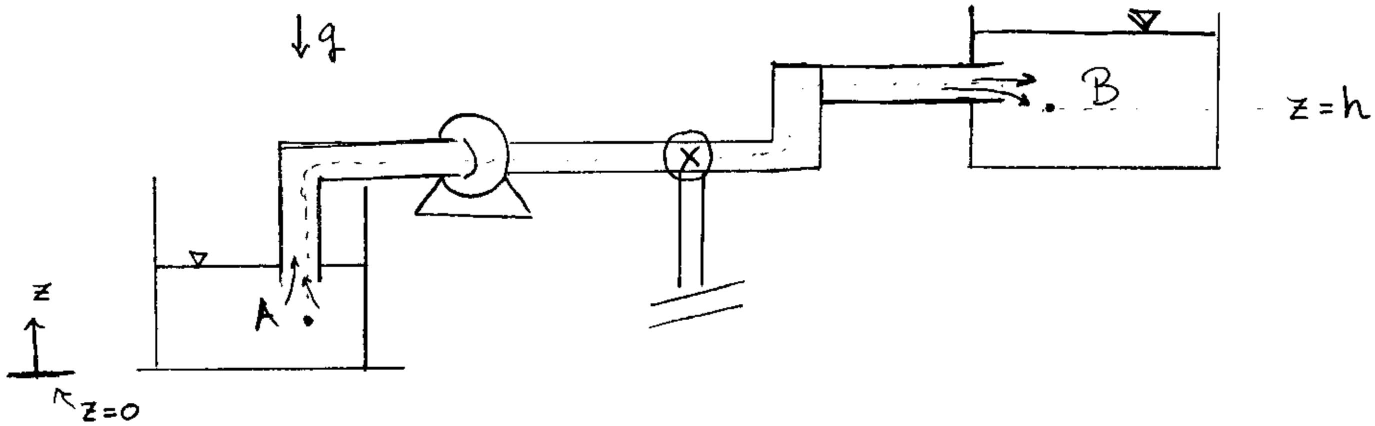
LECTURE 4: THE ISSUES OF CURVES, VALVES, AND REAL STUFF

WE ARE NOW EXPERTS...RIGHT? AT GETTING VALUES OF f FOR GIVEN ENGINEERING PIPING PROBLEMS. NOW WE WILL FINALLY START USING IT. TO MOTIVATE LETS THINK ABOUT THE CHALLENGES OF MOVING FLUID FROM A to B.



IT WILL TAKE ENERGY TO MOVE POINT A TO POINT B. WE MUST DO WORK AGAINST THE FORCE OF GRAVITY.

$$\Delta E = mg\Delta z$$

$$= \rho \forall g h$$

$$\Delta e = \rho g h \qquad \text{(PER UNIT VOLUME)}$$

WE ALSO CAN IDENTIFY OTHER FORMS OF ENERGY THANKS TO OUR FLUIDS ANALYSIS

$$K = \frac{1}{2}\rho V^2 \qquad \text{(KINETIC PER UNIT VOLUME)}$$

$$\{\text{WORK}\} \quad W = P\forall \quad \{\text{PRESSURE} \times \text{VOLUME}\}$$

$$\therefore \quad P = \frac{W}{\forall} \quad \{\text{PRESSURE IS ENERGY PER UNIT VOL}\}$$

LECTURE 4: THE ISSUES OF CURVES, VALVES, AND REAL STUFF

YOU CAN PROBABLY GUESS I'M JUST LISTING TERMS OF BERNOULLI'S EQUATION. YOU SHOULD ALL KNOW BY NOW BERNOULLI'S IS A STATEMENT ABOUT ENERGY CONSERVATION. BUT HOLD ON! WE ALSO SUPPOSEDLY CAN ONLY USE BERNOULLI'S IF CERTAIN ASSUMPTIONS ARE SATISFIED? NAMELY...

i) INVISCID FLOW ($\mu = 0$)

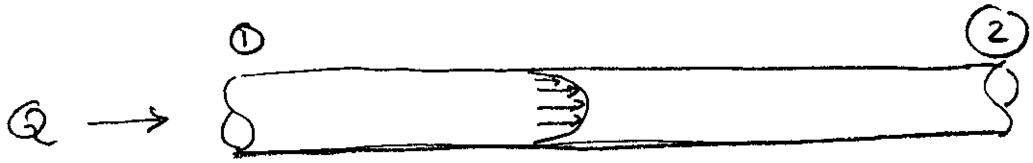
ii) STEADY FLOW ($\partial_t = 0$)

iii) INCOMPRESSIBLE ($\rho = \rho_0$)

iv) IRROTATIONAL ($\nabla \times V = 0$) DON'T WORRY ABOUT THIS ONE

HOW THE HECK ARE WE GOING TO USE BERN IF WE ARE TALKING ABOUT VISCOUS FLOW IN PIPES!?!?

WE WILL JUST ADD A CORRECTION TERM THAT WILL REPRESENT HOW "WRONG" THIS EQUATION IS.



($z_1 = z_2$)

$$P_1 + \cancel{\tfrac{1}{2}\rho V_1^2} + \cancel{\rho g z_1} = P_2 + \cancel{\tfrac{1}{2}\rho V_2^2} + \cancel{\rho g z_2} + \cancel{E_{pump}} - \underbrace{E_{visous}}_{\text{LOST WORK DUE TO THE "FRICTION" OF THE FLUID.}}$$

constant flow rate

same height

no pump yet

ENGINEER LIKE TO DIVIDE THIS EQUATON BY ρg TO MAKE UNITS [LENGTH]. I HAVE NO IDEA WHY.

$$\frac{\Delta P}{\rho g} = \frac{E_{viscous}}{\rho g} = \underbrace{h_L}_{\text{WE CALL THIS "HEAD LOSS"}}$$

LECTURE 4: THE ISSUES OF CURVES, VALVES, AND REAL STUFF

* EXTRA CREDIT WRITE A LITTLE REPORT ON THE HISTORY OF THIS DIVISION BY "ρg" COMES FROM ~500 WORDS. WHY DID ENGINEER TOSS AWAY ENERGY UNITS.

REMEMBER THOSE FRICTION FACTORS! f

$$f = \frac{\Delta P}{\Delta x} \frac{D}{\frac{1}{2}\rho V^2} \qquad (*)$$

WE WILL CONNECT THIS TO OUR HEAD-LOSS EQN NOW.

$$h_L = \frac{\Delta P}{\rho g}$$ SOLVE (*) FOR ΔP, SUB IN!

Major Loss Equation

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

Laminar or Turbulent

$L :=$ Length of Pipe

$D :=$ Diameter of Pipe

$V :=$ Characteristic Velocity

$f :=$ Friction Factor!

WHETHER IT IS LAMINAR OR TURBULENT THIS IS TRUE, ALL THAT CHANGES IS THE f TERM. THAT'S WHY WE GOT SO GOOD AT CALCULATING f's BECAUSE IT COVERS SO MUCH IN JUST ONE NUMBER!

LECTURE 4 : THE ISSUES OF CURVES, VALVES, AND REAL STUFF

A GREAT EXAM QUESTION WOULD BE WHERE DOES VISCOSITY COME INTO PLAY h_L? THERE IS NO μ TERM IN THE EXPRESSION YET IT IS SUPPOSED TO TELL US ABOUT VISCOUS LOSSES.

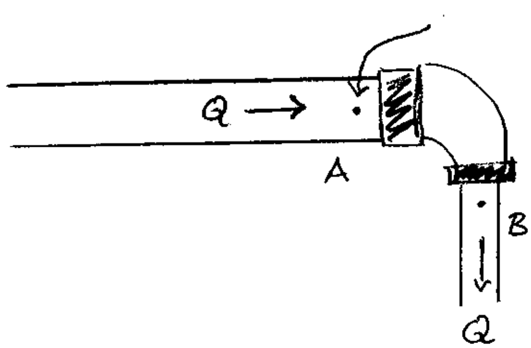
MINOR LOSSES

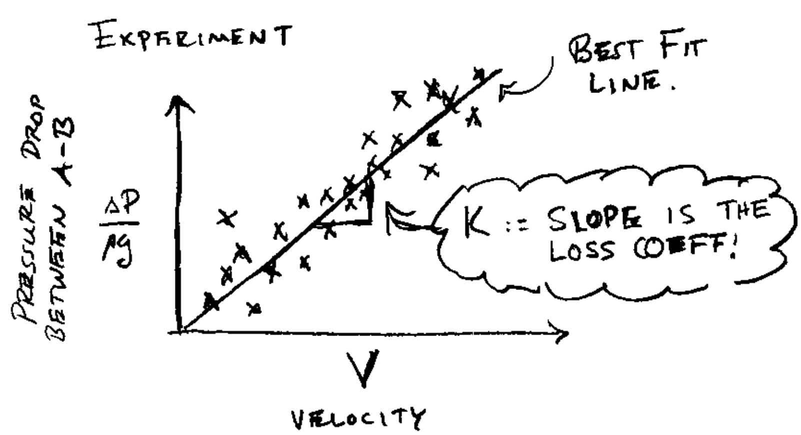
THIS h_L ONLY ACCOUNTS FOR LONG STRAIGHT SECTIONS OF PIPE. (REFER TO THE FIGURE ON pg 1.) WHAT ABOUT THE ELBOWS, THE VALVES, OR SUDDEN EXPANSIONS IN PIPE DIAMETERS?

ENGINEERS ESSENTIALLY JUST TOOK THIS h_L TECHNIQUE AND RAN WITH IT, BUT INSTEAD OF AN EQUATION FOR A TERM LIKE f THEY JUST LUMPED IT INTO AN EXPERIMENTAL COEFFICIENT K.

$$\boxed{h_m = K\frac{V^2}{2g}}$$

$K :=$ dimensionless loss coefficient





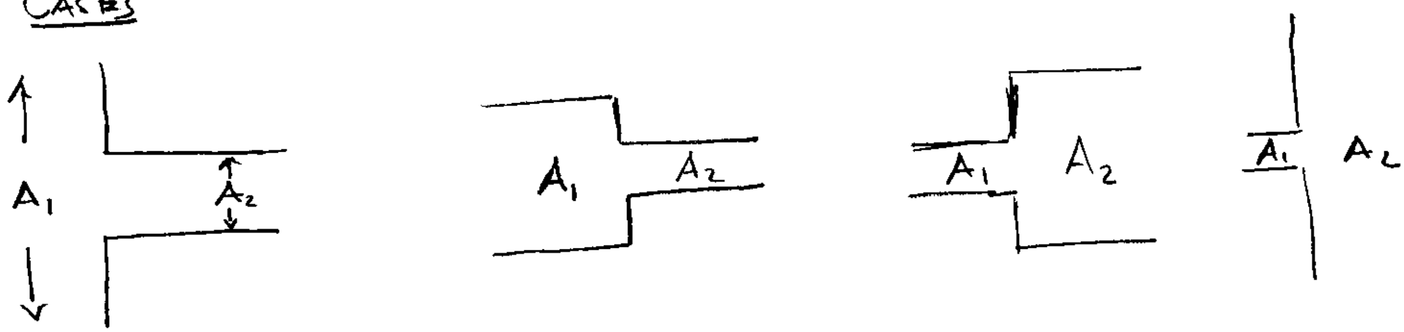
LECTURE 4: THE ISSUES OF CURVES, VALVES, AND REAL STUFF

THIS K VALUE APPLYS TO ALL VALVES, ELBOWS, OR SPLITTERS.

EXPANSIONS & CONTRACTIONS

ANOTHER KIND OF PIPE COMPONENT IS AN AREA CHANGE, THIS INCLUDES ENTRANCE THESE SITUATION REQUIRE THE USE OF TABLES IN THE TEXT (pg 418-419 6th ed)

CASES



$\frac{A_2}{A_1} \sim 0$ (ENTRANCE)

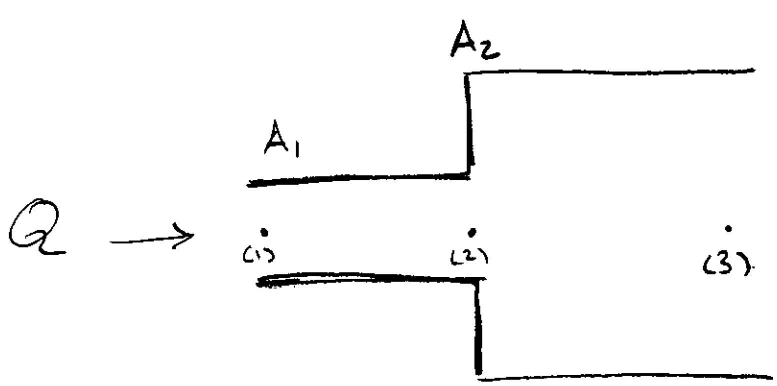
$\frac{A_2}{A_1} < 1$ (CONTRACTION)

$\frac{A_2}{A_1} > 1$ (EXPANSION)

$\frac{A_2}{A_1} = \infty$ (EXIT)

FOR THE CASE OF SIMPLE CONTRACTIONS / EXPANSIONS WE CAN WRITE DOWN A FORMULA FOR K.

(*) $$K = \left(1 - \frac{A_1}{A_2}\right)^2 \quad \text{(EXPANSION)}$$



$A_1 V_1 = A_2 V_3$ (1)

$A_3 (P_1 - P_3) = \rho A_3 V_3 (V_3 - V_1)$ (2)

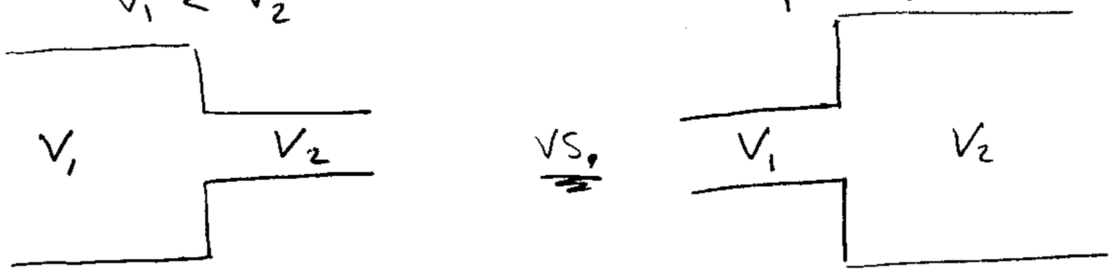
$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} = \frac{P_3}{\rho g} + \frac{V_3^2}{2g} + h_M$ (3)

EXTRA CREDIT USE (1), (2), (3) TO SHOW (*)

LECTURE 4: THE ISSUES OF CURVES, VALVES, AND REAL STUFF

FOR EXPANSIONS / CONTRACTIONS ALWAYS USE THE FASTER VELOCITY!

$V_1 < V_2$ $\qquad\qquad$ $V_1 > V_2$



$$h_m = K\frac{V_2^2}{2g} \qquad\qquad h_m = K\frac{V_1^2}{2g}$$

THE FUNDAMENTAL EQUATION OF ALL PIPING SYSTEMS!

$$\left(\frac{P}{\rho g}+\frac{V^2}{2g}+z\right)_A = \left(\frac{P}{\rho g}+\frac{V^2}{2g}+z\right)_B + \underbrace{h_P}_{\text{PUMP}} - \underbrace{h_L}_{\text{MAJOR}} - \underbrace{h_m}_{\text{MINOR}} \qquad (1)$$

$$h_L = \sum_i^N h_{L,i} = \sum_i^N f_i \frac{V^2}{2g}\frac{L_i}{D_i} = \left\{\begin{matrix}\text{SUM ALL STRAIGHT}\\ \text{SECTIONS OF}\\ \text{PIPE LOSSES}\end{matrix}\right\}$$

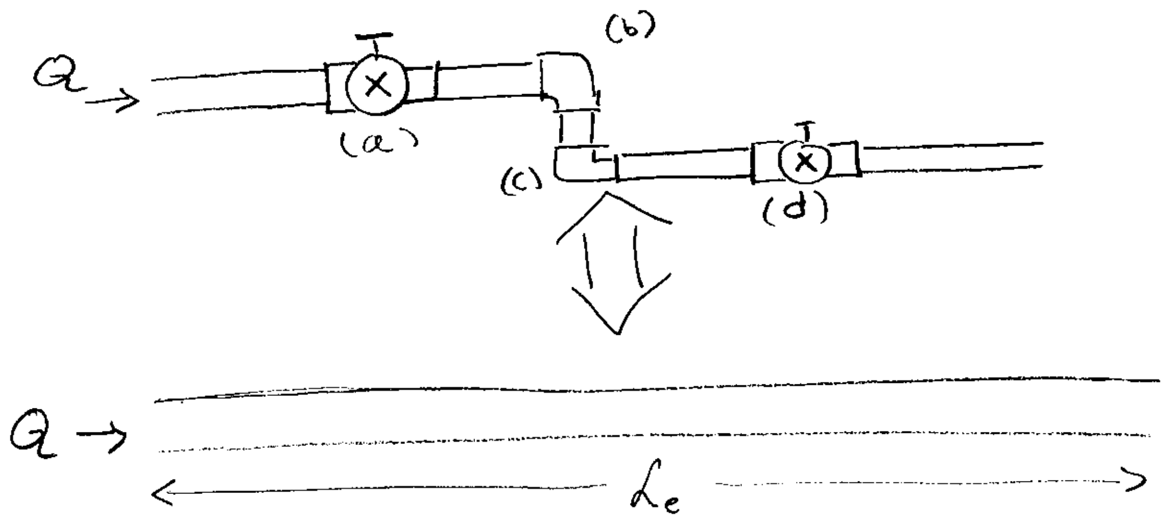
$$h_m = \sum_i^N h_{m,i} = \sum_i^N K_i \frac{V^2}{2g} = \left\{\begin{matrix}\text{SUM OF ALL}\\ \text{COMPONENT}\\ \text{LOSSES}\end{matrix}\right\}$$

* THE LONG STRAIGHT SECTIONS OF PIPE ACCOUNT FOR MOST OF THE HEAD LOSS. AS A RULE OF THUMB IN REAL WORLD PROBLEM FIRST ACCOUNT FOR ALL MAJOR THEN REFINE LATER BY INCLUDING MINOR LOSSES

LECTURE 4: THE ISSUES OF CURVES, VALVES, AND REAL STUFF

EQUIVALENT LENGTH $\mathcal{L}_e$

I ALWAYS LIKED SIMPLIFYING RESISTOR NETWORK IN ELECTRICAL CIRCUITS. THIS IS A SIMILAR GAME. IT LET'S US TURN <u>ALL</u> PIPING SYSTEMS INTO <u>ONE</u> <u>STRAIGHT</u> <u>PIPE</u>!



EACH COMPONENT (a), (b), (c), & (d) HAS ITS OWN RESPECTIVE $\mathcal{L}$. <u>WE STILL NEED THE K'S TO DO THIS BTW</u>

$$h_{m,a} = K_a \frac{V^2}{2g} \overset{!}{=} f \frac{\mathcal{L}_e}{D} \frac{V^2}{2g}$$

WE SET THE LOSS TERM EQUAL TO AN IMAGINARY SECTION OF STRAIGHT PIPE

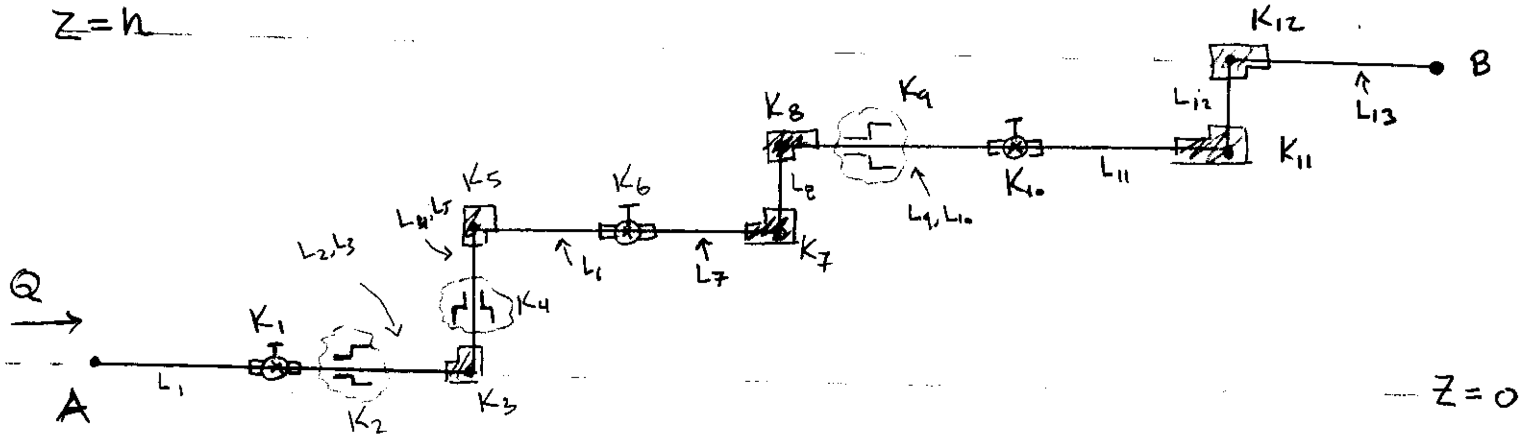
(SOLVE FOR $\mathcal{L}_e$)

$$\mathcal{L}_e = \frac{KD}{f}$$

* YOU DON'T HAVE TO BUT I HIGHLY RECOMMEND ALWAYS CALCULATING $\mathcal{L}_e$ FOR GIVEN PIPE COMPONENTS.

LECTURE 4: THE ISSUES OF CURVES, VALVES, AND REAL STUFF

I IMAGINE THE BENEFIT OF $\mathcal{L}_e$ IS CLEAR JUST BECAUSE A SINGLE STRAIGHT PIPE IS SO SIMPLE. WE ARE BUDGETING ENERGY, WE ARE ANALYZING THE ENERGY REQUIRED TO GET FLUID FROM POINT A TO POINT B.



1) ACCOUNT FOR ALL STRAIGHT SECTIONS OF PIPE

   i) DETERMINE PIPE GEOMETRY

   $$L_i, D_i$$

   ii) LOOK UP ROUGHNESS VALUES FOR EACH SECTION.

   $$\varepsilon$$

   iii) CALCULATE FRICTION FACTORS

   $$f$$

2) ACCOUNT FOR ALL COMPONENTS

   i) LOOK UP/CALCULATE LOSS COEFFICIENTS

   $$K$$

   (OPTIONAL) ii) CALCULATE EFFECTIVE LENGTHS

   $$\mathcal{L}_e$$

SUPER BONUS EXTRA-CREDIT!

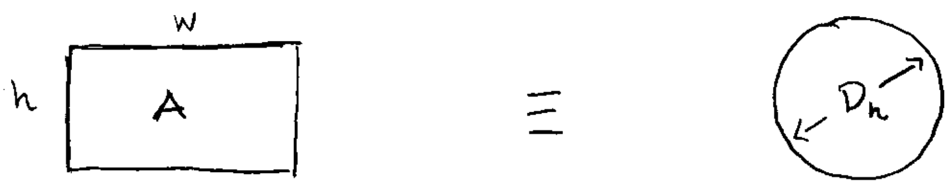
MAKE A "CLASS" IN PYTHON THAT ENCODES <u>EVERYTHING</u> WE'VE DISCUSSED SO-FAR. IT SHOULD HAVE AN _add_ method TO ADD SECTIONS OF PIPE TOGETHER... YOU DEFINITELY DON'T NEED TO DO THIS LOL!

LECTURE 4: THE ISSUES OF CURVES, VALVES, AND REAL STUFF.

THERE IS ONE THING WE HAVEN'T ADDRESSED.

$$\boxed{\text{NON-CIRCULAR PIPES}}$$

ALL OF OUR PIPES HAVE HAD ROUND GEOMETRY. HOW DO SQUARE DUCT CHANGE THE EXPRESSIONS WE'VE DEVELOPED SO FAR? REALLY NOT BY MUCH...



$P = 2w + 2h$

$D_h = \dfrac{4A}{P}$:= Hydraulic Diameter

ALL WE DO IS USE D_h IN ALL THE EXPRESSIONS.

$$f = \frac{\Delta P}{\frac{1}{2}\rho V^2}\,\frac{D_h}{L} \quad \leftarrow \text{hydraulic}$$

$$Re = \frac{\rho V D_h}{\mu} \quad \leftarrow \text{hydraulic}$$

FOR THE f CALCULATIONS IN LAMINAR FLOW FOR NON-CIRCULAR PIPES

$$f_{lam} = \frac{C}{Re}$$

C ← THIS WAS 64 FOR A CIRCULAR PIPE.

Re ← uses D_h hydraulic diameter

* VALUES OF C ARE FOUND TABLE 8.3 IN TEXT. pg 426 in 6th edition.

LECTURE 4 : THE ISSUES OF CURVES, VALVES, AND REAL STUFF

WHEN PEOPLE START TRYING TO USE THIS FRAME-WORK COMMON QUESTIONS / ERRORS ARISE.

1) WHAT SHOULD I USE FOR $\underset{\sim}{V}$ IN ALL THESE EXPRESSIONS!?

$$V = \frac{Q \leftarrow \text{System flow rate (usually required)}}{A \leftarrow \text{Cross-sectional area (could change thru out system)}}$$

2) USING THE WRONG f RELATION FOR NON-CIRCULAR DUCTS. REMEMBER FOR LAMINAR ONLY YOU NEED TO LOOK UP A TABLE THEN CALCULATE.

$$f_{lam,NC} = \frac{C \leftarrow \text{Look up}}{Re \leftarrow \text{use hydraulic diameter}}$$

FOR TURBULENT THE PROCESS IS IDENTICAL, JUST MAKE SURE TO USE D_h IN Re CALC'S

3) CALCULATION ERROR!

YOU CAN SEE ALREADY HOW MUCH BOOK KEEPING THIS CAN BECOME. CALCULATING EACH HEAD LOSS BY HAND, THEN SUMMING, THEN ETC IS PRONE TO ERRORS. THIS IS WHY MAKING EXCEL, PYTHON, MATLAB DO THE CALCULATING FOR YOU IS CRITICAL. JUST MAKE SURE YOU'RE PROGRAMMING THE RIGHT FORMULA!!

4) UNITS

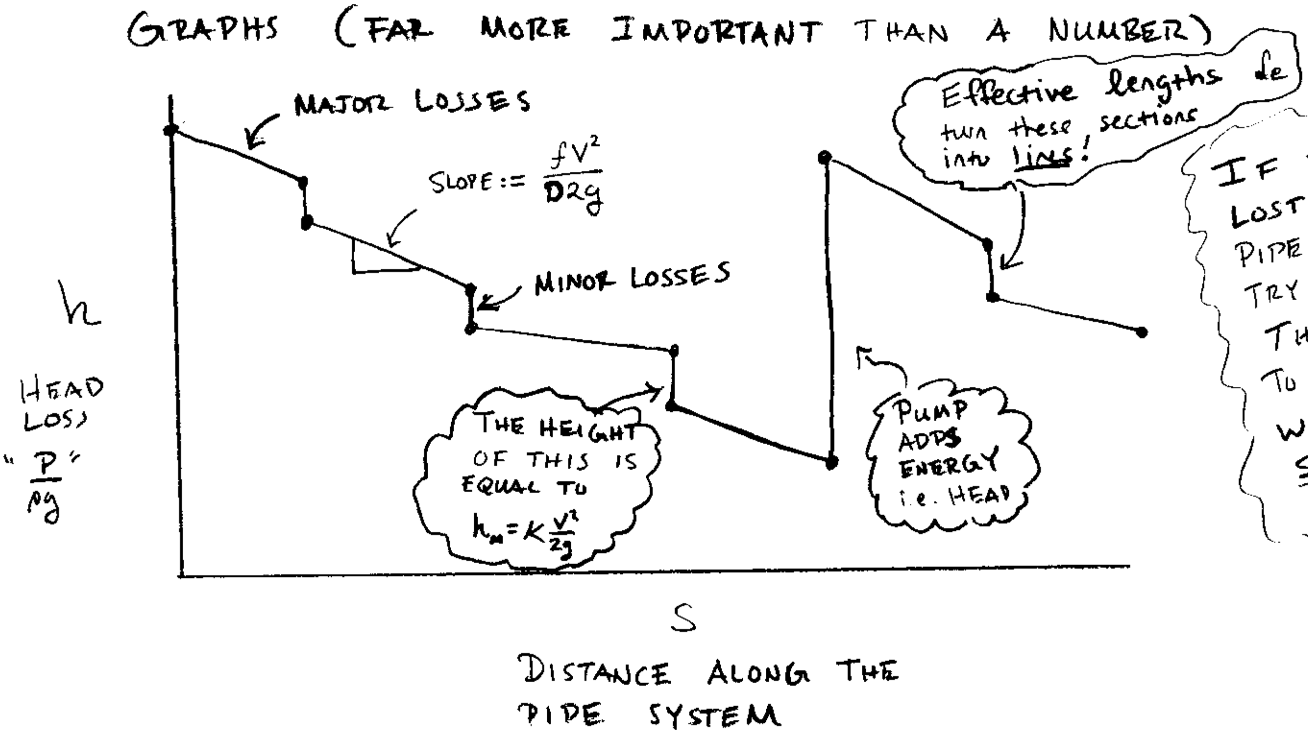
YOU'RE JUNIOR YEAR ENGINEERS... YOU SHOULD BE GOOD AT THIS BY NOW.

5) 2 EQUATIONS 2 UNKNOWNS

THE HEAD LOSS EQUATION IS ONE EQUATION! IF YOU HAVE 2 UNKNOWNS, FUNDAMENTALLY YOU NEED TO INVOKE ANOTHER EQUATION.

LECTURE 4: THE ISSUES OF CURVES, VALVES, AND REAL STUFF

NOW WE CAN UNDERSTAND SYSTEM HEAD LOSS GRAPHS (FAR MORE IMPORTANT THAN A NUMBER)



IF YOU'RE LOST IN A PIPE PROBLEM TRY DRAWING THIS GRAPH TO ESTIMATE WHAT SHOULD HAPPEN!

* 3 TYPES OF PROBLEMS (REF TEXT TABLE 8.4) pg 429 6th ed

A) DETERMINE ΔP or Δh

COMPLEX $\begin{cases} \text{B) DETERMINE } Q \text{ or } V \text{ (SINCE } Q = AV) \\ \text{C) DETERMINE } D \end{cases}$

B & C REQUIRE ITERATIVE ALGORITHMS TO SOLVE. THE LAY-OUT OF THESE IS IN FILE "process.pdf" IN /homework. Shout-out to Gerry Recktenwald for this recipe btw!

EXTRA CREDIT

MAKE MATLAB, PYTHON, ETC. FUNCTIONS THAT IMPLEMENT PROCESSES A, B, C.

I HIGHLY RECOMMEND DOING THIS