ENERGY

- ENERGY = POTENTIAL ENERGY + KINETIC + PRESSURE + $E_{CHEM.}$
- $E_{FRICTION}$ + Q ENERGY ADDED $|_{COOL}^{HEAT}$ + WORK $|_{TURBINE}^{PUMP}$ + $E_{NUCLEAR}$

IN FLUID MECHANIC:

INCOMPRESSIBLE (ρ, V = DO NOT Change)
NO FLUID FRICTION
NO THERMAL ENERGY $Q = 0$

- POTENTIAL ENERGY = ELEVATION OF FLUID $E_z = Zg = Zg/g_c$
- KINETIC ENERGY = FLUID IN MOTION @VELOCITY, $V = \frac{V^2}{2} = \frac{V^2}{2g_c}$
- PRESSURE ENERGY = PRESSURE CONTENT OF FLUID BASED ON WORK DONE ON FLUID $= \frac{p}{\rho} = E_p$
- BERNOULI'S EQUATION = $E_{TOTAL} = E_v + E_p + E_z = \frac{p}{\rho} + \frac{V^2}{2} + Zg$
$= \frac{p}{\rho} + \frac{V^2}{2g_c} + \frac{Zg}{g_c}$
- TOTAL HEAD, TOTAL PRESSURE, TOTAL ENERGY

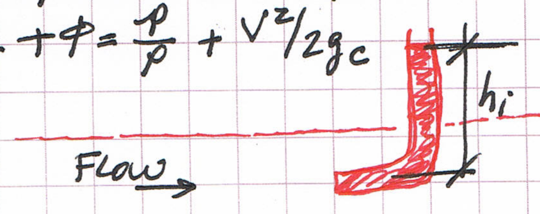
$$h_t = E_t/g = E_t\, g_c/g$$

$$P_t = \rho g h_t = \gamma h_t = \rho h_t (g/g_c)$$

- IMPACT ENERGY (STAGNATION + TOTAL) = Σ POTENTIAL + KINETIC

$$E_i = E_p + E_v = \frac{p}{\rho} + V^2/2 + \phi = \frac{p}{\rho} + V^2/2g_c$$

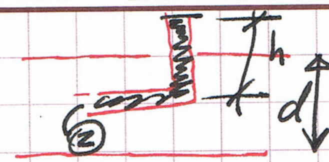
- IMPACT HEAD, $h_i = E_i/g$



PITOT TUBE PIEZOMETER

INSTRUMENTATION

① FLOW →



PITOT TUBE = IMPACT TUBE OR STAGNATION TUBE

PRESSURE ⇄ VELOCITY → PRESSURE ENERGY

$$\frac{P_1}{\rho} + \frac{V_1^2}{2} = \frac{P_2}{\rho} + \frac{V_2^2}{2} \rightarrow 0$$ VELOCITY = 0 @ ②

$$V_1 = \left[\frac{2(P_2 - P_1)}{\rho}\right]^{1/2} = \left[\frac{2g_c}{\rho}(P_2 - P_1)\right]^{1/2}$$

IN REAL LIFE IMPACT FACTOR is a correction factor ≈ 0.99 → 0.995

$V_{actual} = C_i V_{indicated}$ By calcs.

ALL MEASUREMENTS TO BE @ 10d FROM BENDS OR OBSTRUCTIONS.

- HYDRAULIC RADIUS NOT SAME AS PIPE RADIUS

r_h = AREA OF FLUID FLOW / WETTED INSIDE PERIMETER

AREA = CROSS SECTIONAL AREA of FLUID FLOW

PIPE COMPLETELY FULL $r_{h\,PIPE,FULL} = \frac{\pi r^2}{2\pi r} = \frac{r}{2}$

PIPE HALF FULL, $r_{h\,PIPE,HALF} = \frac{\pi r^2/2}{\pi r} = \frac{r}{2}$

- EQUIVALENT DIAMETER, De (HYDRAULIC DIAM)

CHARACTERISTIC DIMENSION

$D_e = 4 r_h$

Absolute Consulting Engineers
Total Design and R&D Engineers
(949) 852-8700
Absoluteco.Com

REVISIONS

DATE: SHEET:
PROJECT:
SUBJECT:
RE:

DETAILS CIVIL . STRUCTURAL . ELECTRICAL . MECHANICAL . PLUMBING . ENERGY . LEED . GREEN ENGINEERING & CONSULTING

REYNOLDS NUMBER, Re

$$Re = \frac{\text{INERTIAL FORCES PUSHING LIQUID FORWARD}}{\text{VISCOUS FORCES IMPEDING LIQUID FLOW}} = \frac{D_e V \rho}{\mu}$$

μ ABSOLUTE VISCOSITY

$$= D_e V \rho/\rho \,/\, \mu/\rho = D_e V/\nu$$

ν KINEMATIC VISCOSITY

G = MASS FLOW RATE = ρV

$$Re = D_e G/\mu = D_e G/\mu g_c$$

LAMINAR FLOW LAMINAE (LAYERS) $Re < 2100$
SMALL CHANNEL, LOW VELOCITY, HIGHLY VISCOUS
STREAMLINES of PARTICLES ON LAYERS

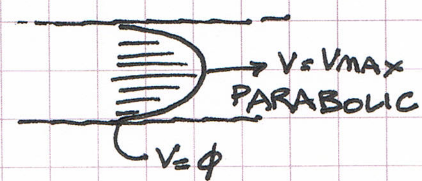
"BUNDLE" a COMPLETE FLUID FLOW

TURBULENT FLOW $Re > 4000$ IRRATIONAL BEHAVIOR
CRITICAL FLOW CRITICAL ZONE, TRANSITION REGION
$2100 < Re < 4000$
HIGHEST RATE of FRICTION LOSS

FLUID VELOCITY DISTRIBUTION

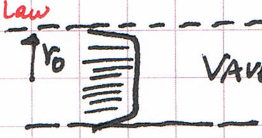
LAMINAR: $V_{AVE} = \frac{\dot{V}\ (\text{VOLUME FLOWRATE})\ (\text{VELOCITY})}{A} = \frac{V_{max}}{2}$

$\dot{V}$ = VOLUMETRIC FLOWRATE



TURBULENT $V_r = V_{max}\left(\frac{r_0 - r}{r_0}\right)^{1/7}$ 1/7 POWER LAW

$Re \sim 10^5$



$V_{AVE} = V_{max}\,(0.817)$ 49/60

$V_{AVE}/V_{max} = 0.75$ @ $Re = 4000$

$0.75 \rightarrow 0.86$ @ $10^6 = Re$

$\frac{V_{AVE}}{V_{max}}$ = 0.75 $Re = 4000$
= 0.817 1/7 POWER $Re = 10^5$
= 0.86 $Re = 10^6$

TYPES OF FLOWS: . LAMINAR (VISCOUS OR STREAMLINE) $Re < 2100$
CREEP "IDEAL"
. (CRITICAL) MID RANGE VERY LOW $2000 \le Re < 4000$
TRANSITIONAL
. TURBULENT $Re > 4000$

Re = RATIO of $\frac{\text{INTERTIA}}{\text{VISCOUS}} = \frac{DV\rho}{\mu} = \frac{\text{DIAMETER VELOCITY}}{\text{ABSOLUTE VISCOSITY / FLUID DENSITY}}$

LAMINAR: FRICTION FACTOR $f = 64/Re$ NOT FUNCTION of PIPE MAT'L
TURBULENT: $f = [Re(DV, \mu, \rho), \epsilon/D$ ROUGHNESS OF PIPE $]$
VERY COMPLEX

$Re = (3''\text{ PIPE}, 4\text{ Ft/SEC})\text{ WATER} = (3/12\ \text{Ft})(4\ \text{Ft/s})(62.5\#/\text{Ft}^3)/0.0005\ \mu = 125{,}000 > 2100$

CRITICAL MIN VELOCITY	50°F	0.676	0.338	0.169	140°F	0.247	0.124	0.0617
PIPE DIAMETER		1/2"	1"	2"		1/2"	1"	2"

MODELING

SIMILARITY (PROTOTYPE) →
- MECHANICAL
- GEOMETRIC
- DYNAMIC
- VISCOUS VS INERTIA
- INERTIA VS GRAVITATIONAL
- SURFACE TENSION

MECHANICAL = GEOMETRIC & DYNAMIC

GEOMETRIC = GEOMETRIC SCALING

L_r = (SIZE of MODEL)/(SIZE of PROTOTYPE)

$\frac{A_m}{A_p} = (L_r)^2$; $V_m/V_p = (L_r)^3$

DYNAMIC = RATIO of ALL FORCES: INERTIA, gravity, VISCOSITY, ELASTICITY, FLUID COMPRESSIBILITY, TENSION, PRESSURE

VISCOSITY/INERTIA; INERTIA/GRAVITY; INERTIA/SURFACE TENSION

DISTORTED MODELS: BASED ON GEOMETRIC MODELING. SINCE DYNAMIC RATIOS MAY NOT APPLY

DYNAMIC VARIATIONS

Reynolds NUMBER

$\frac{L_m V_m}{\nu_m}$ $Re_m = Re_p = \frac{L_p V_p}{\nu_p}$

INERTIA/VISCOUS

- TORPEDOES / SUBMARINES
- AIRFOILS/AIRCRAFT SUBSONIC
- TURBINE/PUMPS/FANS
- DRAINAGE THRU TANKS
- CLOSED PIPES
- FLOW meters
- OPEN CHANNEL (NO WAVE)

INERTIA VS GRAVITY

$Fr = \frac{V^2}{Lg}$

$\frac{V_m^2}{L_m g} = Fr_m = Fr_p = \frac{V_p^2}{L_p g}$

$Re_m = Re_p$

⇓

$\frac{\nu_m}{\nu_p} = \left(\frac{L_m}{L_p}\right)^{3/2} = (L_r)^{3/2}$

(SOMETIMES) PARTIALLY SIMILAR

- SURFACE SHIPS, BOW WAVES
- OSCILLATORY/SURFACE WAVES
- SURGE & FLOODS
- SPILLWAYS, WEIRS
- OPEN CHANNEL
- motion of Fluid Jet

SURFACE TENSION

Weber #

$We = \frac{V^2 L \rho}{\sigma} = \frac{\text{INERTIA}}{\text{SURFACE TENSION}}$

$We_m = We_p$

- AIR ENTRAPMENTS
- BUBBLES
- DROPLETS
- WAVES

A PROTOTYPE HEAD DISCHARGING RATING CURVE FOR 108 in NEEDLE VALVE IS TO OPERATE AT MAX. HEAD OF 200 Ft H_2O. A 6" INCH MODEL IS AVAILABLE. COEFFICIENT OF DISCHARGE FOR OPEN POSITION IS 0.6 ($Q = CA\sqrt{2gH}$; H TOTAL HEAD MEASURED ONE DIAMETER UPSTREAM OF VALVE & A IS AREA BASED ON DIAMETER UPSTREAM

A. COMPUTE THE MODEL DISCHARGE TO SATISFY REYNOLD'S LAW FOR Q_{max}.

B. WHAT IS MODEL MAXIMUM Q & H_{max} ?

ν @ 50°F = 1.4×10^{-5} Ft²/s ; SCALE RATIO = $\frac{6}{108} = \frac{1}{18}$

A. $Re = \frac{VD}{\nu}$; $Re|_p = Re|_m \Rightarrow \frac{VD}{\nu}\Big|_p = \frac{VD}{\nu}\Big|_m \Rightarrow \frac{VD|_m}{VD_p} = 1$

$\frac{V_m}{V_p}\frac{D_m}{D_p} = 1 = \frac{V_m}{V_p}\frac{1}{18} = 1 \rightarrow$ OR $\frac{V_m}{V_p} = 18$

$Q_p = CA\sqrt{2gH} = (0.6)\frac{\pi}{4}\left(\frac{108}{12}\right)^2\sqrt{2(32.2)*200} = 4330\text{CFS}$

$V_p = \frac{Q_p}{A_p} \rightarrow V_m = (V_p)18 = \frac{Q_p(18)}{A_p}$

FLUID DYNAMICS

CONVERSATION OF ENERGY

$\rho_{H_2O} = 62.4 \frac{lbm}{ft^3}$

BERNOULI'S EQUATION

$$E_t = E_P + E_V + E_Z + E_E + E_f + E_m$$

$$= \frac{P}{\rho} + \frac{V^2}{2g_c} + \frac{Zg}{g_c}$$

$$V = \frac{Q}{A}$$

$$\dot{m}_1 = \dot{m}_2 = \rho_1 A_1 V_1 = \rho_2 V_2 A_2$$

FRICTION FACTOR

$$f \left(\underset{\text{LAMINAR}}{Re < 2100}\right) = \frac{64}{Re}$$

$$f \left(\underset{\text{TURBULENT}}{Re > 2100}\right) = 0.25 \Big/ \left[\log_{10}\left(\frac{\frac{\epsilon}{D}}{3.7} + \frac{5.74}{Re^{0.9}}\right)\right]^2$$

LOOK UP MOODY DIAGRAM P. 17-6

$$h_f(ft, head) = \frac{fLV^2}{2Dg} \; ; \; \Delta P_f(\text{PRESSURE}) = h_f \rho \left(\frac{g}{g_c}\right)$$

$$E_f = h_f \left(g/g_c\right)$$

TO FIND PIPE SIZE, D: ITERATIVE SOLUTION

Absolute Consulting Engineers
Total Design and R&D Engineers
(949) 852-8700
Absoluteco.Com

REVISIONS

SHEET NUMBER 1
JOB NAME: HYDRAULICS
RE: SIMILITUDE
DATE 9/07/04

DETAILS — ENGINEERING & CONSULTING

A PROTOTYPE HEAD DISCHARGING RATING CURVE FOR 108 in NEEDLE VALVE IS TO OPERATE AT MAX. HEAD OF 200 Ft H_2O. A 6" INCH MODEL IS AVAILABLE. COEFFICIENT OF DISCHARGE FOR OPEN POSITION IS 0.6 ($Q = CA\sqrt{2gH}$; H TOTAL HEAD MEASURED ONE DIAMETER UPSTREAM OF VALVE & A IS AREA BASED ON DIAMETER UPSTREAM

A. COMPUTE THE MODEL DISCHARGE TO SATISFY REYNOLD'S LAW FOR Q_{max}.

B. WHAT IS MODEL MAXIMUM Q & H_{max} ?

ν @ 50°F = 1.4×10^{-5} Ft²/s ; SCALE RATIO = $\frac{6}{108} = \frac{1}{18}$

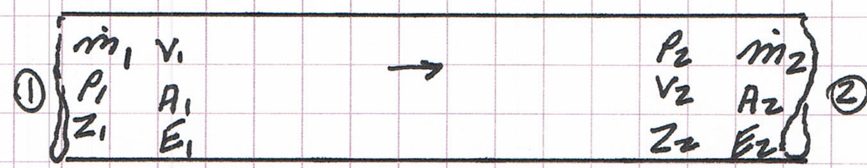
A. $Re = \frac{VD}{\nu}$; $Re|_p = Re|_m \Rightarrow \frac{VD}{\nu}\Big|_p = \frac{VD}{\nu}\Big|_m \Rightarrow \frac{VD|_m}{VD_p} = 1$

$$\frac{V_m}{V_p}\frac{D_m}{D_p} = 1 = \frac{V_m}{V_p}\frac{1}{18} = 1 \rightarrow \text{OR } \frac{V_m}{V_p} = 18$$

$$Q_p = CA\sqrt{2gH} = (0.6)\frac{\pi}{4}\left(\frac{108}{12}\right)^2\sqrt{2(32.2)*200} = 4330\text{CFS}$$

$$V_p = \frac{Q_p}{A_p} \rightarrow V_m = (V_p)18 = \frac{Q_p(18)}{A_p}$$

HYDRO (FLUID) DYNAMICS



- $\dot{m}_1 = \dot{m}_2$ MASS FLOW RATE SAME (CONSERVATION of MASS)

$\rho_1 V_1 A_1 = \rho_2 V_2 A_2$ CONTINUITY EQUATION

$\dot{V}_1 = \dot{V}_2 = V_1 A_1 = V_2 A_2$ IF FLUID IS INCOMPRESSIBLE $\rho_1 = \rho_2$

$V_1 = V_2$ IF AREA 1 = AREA 2, SAME VELOCITIES
PIPE CAN ZIGZAG & WIND, IF WE IGNORE FRICTION. ALL OF ABOVE IS TRUE.
$\therefore E_1 = E_2$

FRICTION: IF PIPE HAS SURFACE ROUGHNESS, THEN FRICTION EXIST
$E_1 = E_2 + E_F$ OR $E_2 < E_1$

IF $Z_1 = Z_2$ & IF $V_1 = V_2$; ONLY CHANGE WILL BE $P_2 - P_1 = \Delta P_f$ PRESSURE DROP

ΔP = CHANGE IN PRESSURE ENERGY WITHIN FLUID
= function of (SPECIFIC ROUGHNESS ϵ, VELOCITY, D, ...)
ϵ = SPECIFIC ROUGHNESS; ϵ/DIAMETER = RELATIVE ROUGHNESS

	ϵ, ft	ϵ, m
PLASTIC (PVC, & ABS)	5.0×10^{-6} ft	1.5×10^{-6} m
COPPER, BRASS	5×10^{-6}	1.5×10^{-6}
STEEL	2×10^{-4}	6×10^{-5}
CAST IRON	8×10^{-3}	2.4×10^{-3}
CONCRETE	4×10^{-3}	1.2×10^{-3}

FLUID DYNAMICS

CONVERSATION OF ENERGY

$\rho_{H_2O} = 62.4 \frac{lbm}{ft^3}$

BERNOULI'S EQUATION

$$E_t = E_P + E_V + E_Z + E_E + E_f + E_m$$

$$= \frac{P}{\rho} + \frac{V^2}{2g_c} + \frac{Zg}{g_c}$$

$$V = \frac{Q}{A}$$

$$\dot{m}_1 = \dot{m}_2 = \rho_1 A_1 V_1 = \rho_2 V_2 A_2$$

FRICTION FACTOR

$$f \underset{\text{LAMINAR}}{(Re < 2100)} = \frac{64}{Re}$$

$$f \underset{\text{TURBULENT}}{(Re > 2100)} = 0.25 \Big/ \left[\log_{10}\left(\frac{\frac{\epsilon}{D}}{3.7} + \frac{5.74}{Re^{0.9}}\right)\right]^2$$

LOOK UP MOODY DIAGRAM P. 17-6

$$h_f(\text{ft, head}) = \frac{fLV^2}{2Dg} \;;\; \Delta P_f(\text{PRESSURE}) = h_f \, \rho \left(\frac{g}{g_c}\right)$$

$$E_f = h_f\left(g/g_c\right)$$

TO FIND PIPE SIZE, D: ITERATIVE SOLUTION

IDEAL FLOW

ϕ = STREAM POTENTIAL FUNCTION, VELOCITY POTENTIAL FUNCTION

$= \Sigma \phi_x, \phi_y, \phi_z = \phi_x(x,y) + \phi_y(x,y)$ Z NOT SHOWN

u = VELOCITY COMPONENT IN X DIRECTION $= \frac{\partial \phi}{\partial x}$; lly, $v = \frac{\partial \phi}{\partial y}$

TOTAL DERIVATIVE OF STREAM FUNCTION $d\phi = \frac{\partial \phi}{\partial x}dx + \frac{\partial \phi}{\partial y}dy$

$d\phi = u\,dx + v\,dy$

EQUIPOTENTIAL LINE WHERE ϕ IS CONSTANT $d\phi = \phi$ ZERO

$d\phi = 0 = u\,dx + v\,dy \rightarrow dy/dx$ @ EQUIPOTENTIAL $= -u/v$

STREAM FUNCTION (LAGRANGE STREAM FUNCTION), $\psi(x,y)$

$u = \partial \psi / \partial y$; $v = -\partial \psi / \partial x$; $d\psi = \frac{\partial \psi}{\partial x}dx + \frac{\partial \psi}{\partial y}dy$

$d\psi = -v\,dx + u\,dy$ (when $d\psi = 0$) $\frac{dy}{dx} = \frac{v}{u}$

$d\psi = 0 \Rightarrow$ EACH STREAM LINE REPRESENTS CONSTANT VALUE ψ

- EQUIPOTENTIAL LINES, ϕ = CONSTANT = POROUS, PERMEABLE, PRESSURE SAME
- IDEAL, NON VISCOUS FLUID, $\tau = 0$ (FRICTIONLESS) ϕ HAS NO PHYSICAL quantity

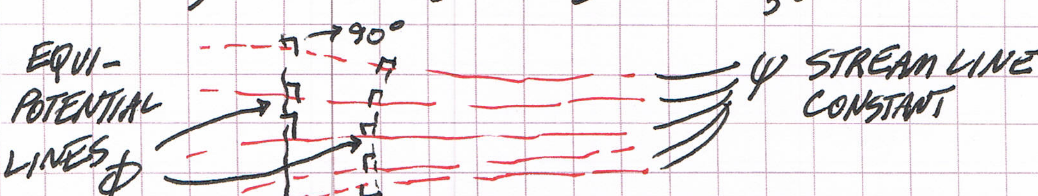
Say $\phi = 4xy^2 - 3x$

$u = \frac{\partial \phi}{\partial x} = 4y^2 - 3$; $v = \frac{\partial \phi}{\partial y} = 8xy - 3x$ } $u = \frac{\partial \psi}{\partial y}$; $v = -\frac{\partial \psi}{\partial x}$

$\int u\,dy = \psi = \int (4y^2 - 3)\,dy = \frac{4y^3}{3} - 3y + C_1$

$-\int v\,dx = \psi = \int (8xy - 3x)\,dx = \frac{8x^2y}{2} - \frac{3x^2}{2} + C_2$

$\psi = \frac{4y^3}{3} - 3y + C_1 + \frac{8x^2y}{2} - \frac{3x^2}{2} + C_2 = \frac{4}{3}y^3 + 4x^2y - 1.5x^2 - 3y + C$

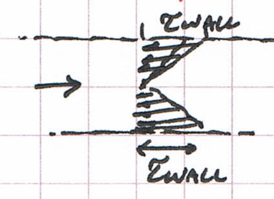


REVISIONS

DATE: SHEET:
PROJECT:
SUBJECT:
RE:

SHEAR STRESS IN CIRCULAR PIPES

- $\tau = \mu \frac{dv}{dy}$ SHEAR STRESS BASED ON VISCOUS FRICTION



$r = D/2$

- CIRCULAR PIPE

$\tau = \mu \frac{dv}{dr}$

IN TURBULENT FLOW SHEAR STRESS IS BASED ON MOMENTUM EFFECT

$\tau = (P_1 - P_2)\, r/2L$

$= \frac{f \rho V^2}{8}$ @ $r = D/2$

$\tau = (P_1 - P_2)\frac{r}{2L}$

$\tau = \frac{\Delta P \, r}{2(\Delta L)}$

SAME

$f = 64/Re$ @ LAMINAR

$\Delta P = h_f(\rho g)$; $h_f = \frac{fLV^2}{2Dg}$

$\tau = h_f(\rho g)\, r/2L = \frac{fLV^2}{2Dg}\rho g \frac{D/2}{2L}$

$= \frac{f \rho V^2}{8}$

$\frac{dP}{dL} = 4\tau_{wall}/D$

E_f = Hagen Poiseuille EQN

$= \frac{32 \mu V L}{D^2 \rho}$

$\tau = \frac{16 \mu V r}{D^2}$

@ PIPE WALL $r = \frac{D}{2}$; $\tau_{wall} = \frac{8 \mu V}{D}$

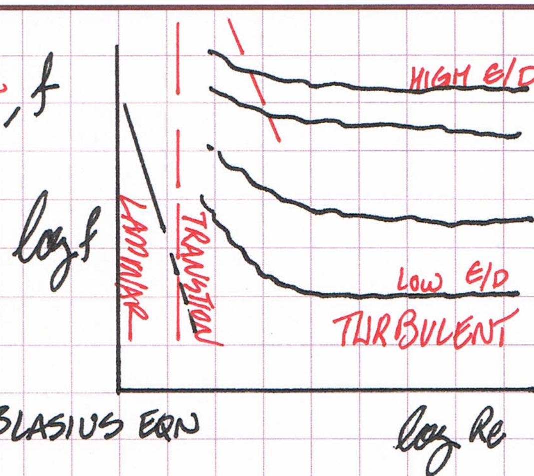
Absolute Consulting Engineers
Total Design and R&D Engineers
(949) 852-8700
Absoluteco.Com

REVISIONS

DATE: SHEET:
PROJECT:
SUBJECT:
RE:

DETAILS CIVIL . STRUCTURAL . ELECTRICAL . MECHANICAL . PLUMBING . ENERGY . LEED . GREEN ENGINEERING & CONSULTING

FRICTION FACTOR, f



Re < 2100, LAMINAR: $f = \frac{64}{Re}$ DARCY EQN.

CHEMICAL INDUSTRY $f_{DARCY} = 4 f_{FANNING}$

3000 < Re < 100,000, TURBULENT $f = \frac{0.316}{Re^{0.25}}$ BLASIUS EQN

NIKURADSE EQUATION (SMOOTH PIPE $\epsilon/D = 0$) [Re = VERY LARGE (?) USE OTHER EQNS]

$$\frac{1}{\sqrt{f}} = 2.0 \log_{10}(Re\sqrt{f} - 0.80)$$

KARMAN - NIKURADSE @ VERY LARGE Re; $\frac{1}{\sqrt{f}} = 1.74 - 2\log_{10}\left(\frac{2\epsilon}{D}\right)$

NIKURADSE DOES NOT HAVE E/D. COLEBROOK DOES HAVE E/D.

COLEBROOK EQUATION: $1/\sqrt{f} = 2\log_{10}\left[\epsilon/D / 3.7 + 2.51/(Re\sqrt{f})\right]$

SWAMEE & JAINE EQUATION: 1% ERROR $10^{-6} < \epsilon < 0.01$; $5\times10^{3} < Re < 1\times10^{8}$

BETTER THAN MOODY DIAGRAM $f = 0.25 / \left[\log_{10}\left[\frac{\epsilon/D}{3.7} + \frac{5.74}{Re^{0.9}}\right]\right]^2$

MOODY DIAGRAM IS YET ANOTHER METHOD TO DETERMINE f.

FRICTION ENERGY LOSS

$h_f = \left[z_1 + p_1 + \frac{V_1^2}{2g}\right] - \left[z_2 + p_2 + \frac{V_2^2}{2g}\right]$

LAMINAR

$f = 64/Re$ DARCY EQUATION

$h_f = fLV^2/2Dg$; $\frac{\rho f L V^2}{144 D (2g)}$ psi (ρ: lb/ft³, L: ft, V: fps, D: ft)

$E_f = fLV^2/2D = fLV^2/2Dg_c$

E_f [CIRCULAR PIPE & LAMINAR] =

$E_f = \frac{32\mu VL}{D^2\rho} = \frac{32\mu VLg_c}{\rho D^2 g}$; $V = \frac{\dot V}{A}$

$E_f = 128\mu \dot V L / \pi D^4 \rho = 128\mu \dot V L g_c / \pi D^4 \rho$

$\Delta P = H_f \times \rho g = H_f \times \rho g/g_c$

$\dot V$: FLOW RATE gpm

d = INCHES DIAMETER

L = Ft, LENGTH

h = Ft, HEAD

P = PRESSURE psi

BRASS & COPPER

$h = 6.23 \times 10^{-4} \dot V^2 \frac{L}{d^5}$

$P = 2.7 \times 10^{-4} \frac{L}{d^5} \dot V^2$

COPPER/BRASS $f \approx 0.02$

STEEL ($f \approx 0.04$)

$h = 1.24 \dot V^2 \times 10^{-3} \frac{L}{d^5}$

$P = 5.39 \times 10^{-3} \dot V^2 \frac{L}{d^5}$

TURBULENT

$h_f = \frac{fLV^2}{2Dg}$; $\Delta P = h_f \times \rho g = h_f(\rho g/g_c)$

HAZEN WILLIAMS EQUATION

$h_f = 3.022 V^{1.85} L / (C^{1.85} D^{1.165})$

$= 10.44 L (\dot V_{gpm})^{1.85} / C^{1.85} * d_{inches}^{4.865}$

$\nu > 1.2 \times 10^{-5}$ ft²/s @ 60°F

FLOW RATE EQNS

$\dot V \propto d^{5/2}\left(\frac{h}{L}\right)^{1/2}$

$\propto d^{5/2}(P/L)^{1/2}$

BRASS & COPPER

$\dot V = 40.1 d^{5/2}(h/L)^{1/2}$

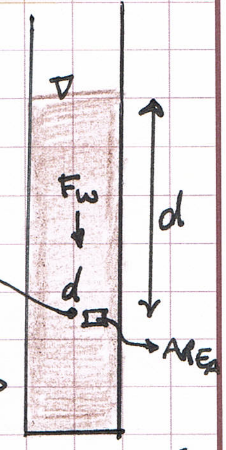
$\dot V = 60.8 d^{5/2}(P/L)^{1/2}$

FOR OTHER THAN PIPE GEOMETRY USE EQUIVALENT De HYDRAULIC DIAMETER

ENERGY CONTENT OF FLUID

STATIC HEAD:

WEIGHT of WATER ABOVE DISTANCE "d" GIVES PRESSURE EXERTED @ POINT d, POTENTIAL ENERGY CONTENT, #/in², #/ft², ...



(PSF) $P = \rho_{density}(PCF) * d(DISTANCE)$

(PSi) $P = \frac{\rho d}{144}$

- HEAD
- STATIC HEAD
- HYDRO-STATIC HEAD
- PRESSURE HEAD
- HYDROSTATIC PRESSURE

1 Ft of HT @ 50°F $P = \frac{62.4}{144}(1 ft) = 0.433$ Psi

1 Ft of H_2O @ 50°F = 0.433 Psi OR

$d = P\frac{144}{\rho} = (1 Psi)\frac{144}{62.4} = 2.31$ Ft of HEAD (PRESSURE H_2O @ 50°F)

VELOCITY HEAD

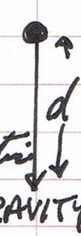
ANY MATERIAL INCLUDING FLUID IN MOTION IS IN BOUNDARY of KINETIC ENERGY. → TOTAL ENERGY − STATIC HEAD = VELOCITY HEAD

DYNAMIC OF FALLING OBJECT: $d = \frac{gt^2}{2}$, distance to time

V = acceleration * time
$= gt$

g = gravity acceleration

$d = V^2/2g$



TOTAL ENERGY CONTENT:

VELOCITY HEAD + (STATIC HEAD) POTENTIAL HEAD

RELATIVE PHYSICAL + PRESSURE EXERTED

SEE BERNOULI'S EQUATION

FRICTION LOSS STEAM & GASES

- LESS THAN $M < 0.3$, ρ = INCOMPRESSIBLE OR $\Delta\rho$ = is less THAN 10%

  $V = \dot{m} / \rho_{AVE} A$ $Re = DG/\mu$

  G = CONSTANT MASS FLOW RATE PER UNIT AREA = $V_{AVE} \rho_{AVE}$

  $\Delta P_f = P_1 - P_2 = \rho_{ave} h_f = fLG^2 / 2D\rho_{AVE}$

- PERFECT GAS WITH MOLECULAR WEIGHT of MW

  T (ABSOLUTE TEMPERATURE, °R, °K), $\rho_{ave} = (P_1 + P_2)/2$

  $P_1^2 - P_2^2 = fLG^2 R^* T / D(MW) = fLG^2 R^* T / Dg_c MW$

Absolute Consulting Engineers
Total Design and R&D Engineers
(949) 852-8700
Absoluteco.Com

REVISIONS

DATE: SHEET:
PROJECT:
SUBJECT: $Q = AV$
RE:

DETAILS CIVIL . STRUCTURAL . ELECTRICAL . MECHANICAL . PLUMBING . ENERGY . LEED . GREEN ENGINEERING & CONSULTING

$Q = AV$

WHAT SIZE PIPE WILL 195GPM @ 5FPS ?

(a) CONVERT GPM TO Ft^3/sec

$$Q = 195\,GPM = 195\frac{G}{min}\left(\frac{1\,min}{60\,sec}\right)\left(\frac{Ft^3}{7.48\,G}\right) = \quad 0.434\,Ft^3/s$$

$$A = \frac{\pi D^2}{4} = \frac{Q}{V} = \frac{0.434}{5}\frac{Ft^3/sec}{Ft^2} = 0. \quad 0.0868\,Ft^2/s$$

$$D = \sqrt{D^2} = \sqrt{(0.0868)\frac{4}{\pi}} = (2)(0.166)Ft\left(\frac{in}{Ft}\right)12 \quad (. \; 4\text{ INCH}:$$

OPTION (b)

$$q = GPM = 2.448\,d^2 V$$

q = GPM
d = in
V = Ft/s

$$d = \sqrt{d^2} = \sqrt{\frac{q}{2.448\,V}}$$

$$= \left[\frac{195}{2.448(5\,Ft/s)}\right]^{1/2}$$

$$\cong 4''$$

$d = 4''$

BERNOULI'S EQUATION

SIMPLER ENERGY EQUATION: CONSERVATION OF ENERGY

$$\Sigma E_{=0} = (\text{STATE})_1 - (\text{STATE})_2$$

$$= \left(Z_1 + d_1 + \frac{V_1^2}{2g}\right) - \left(Z_2 + d_2 + \frac{V_2^2}{2g} + h_f\right)$$

$\frac{V_1^2}{2g}$: KINETIC ENERGY

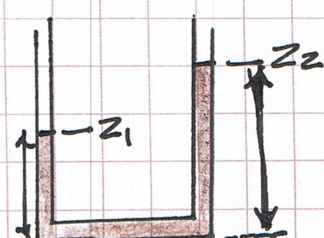
$Z_2 + d_2$: POTENTIAL ENERGY

h_f: FRICTION HEAD, FRICTION LOSS ENERGY

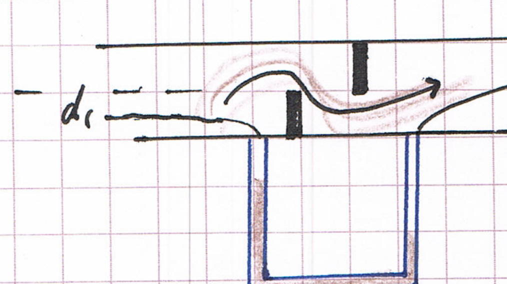
POTENTIAL ENERGY CONTENT IS IN TWO PARTS:

STATIC HEAD & POSITION HEAD

POSITION HEAD IS SIMPLY A RELATIVE PHYSICAL POSITION

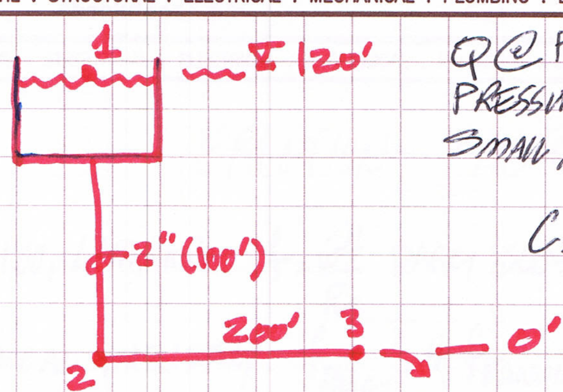


$Z_2 - Z_1 =$ IS ONLY REFERENCE TO EACH OTHER & any REFERENCE IS CANCELLED OUT.



d_1 & d_2 are pressure head @ THESE LOCATION

A PUMP OR ELEVATION CAUSES MOTION & ENERGY WITHIN WATER



Q @ POSITION 2 ? OR 3?
PRESSURE @ POSITION 2 ? OR 3?
SMALL / MINOR LOSSES ARE IGNORED.

C = 140 COPPER

STATIC HEAD + POTENTIAL + VELOCITY HEAD$|_1$ = STATIC HEAD + POTENTIAL + VELOCITY HEAD$|_2$ + h_f

@ 1 : THE BASE IS SO WIDE THAT VELOCITY IS ZERO ∴ VELOCITY HEAD = ϕ

@ 2 : ALL THREE COMPONENTS EXIST

@ 3 : AFTER IT DISCHARGES VELOCITY HEAD ONLY WHICH IS BASED ON PRESSURE JUST BEFORE IT DISCHARGES.

$$Z_1 + d_1 + \frac{V_1^2}{2g} = Z_3 + d_3 + \frac{V_3^2}{2g} + h_f$$

$$120 + 0 + 0 = 0 + 0 + 0 + h_f$$

ASSUME FOR NOW ↑

$Z_1 = 120'$
d_1 = NO POTENTIAL E.
V_1 = VERY SLOW
$Z_3 = 0'$
d_3 = WATER IN ATMOS. = 0
V_3 = NEARLY NO VELOCITY
ALL ENERGY GONE (?) ASSUMPTION

$Z_1 = h_f$

$$120' = h_f = 0.0021\, L \left(\frac{100}{C}\right)^{1.85} \frac{q^{1.85}}{d^{4.866}}$$

$L = 300$ Ft
$C = 140$
$d = 2"$

$q = 177$ GPM

IN REALITY $q = AV$ SOLVE FOR V PLACE IN $\frac{V_3^2}{2g}$ REDO TILL VELOCITY IS SAME BY ITERATION

WHAT IS VELOCITY OF A FLOW WITH Re=2000 IN A 6" PIPE @ 60°F?

$$Re = \frac{DV}{\nu} = 2000 = \frac{(6''/12)\ V\ Ft/s}{\nu\ Ft^2/s}$$

ν = KINEMATIC VISCOSITY, Ft^2/s
$= 1.21 \times 10^{-5}$ H_2O @ 60°F

$$Re = 2000 = \frac{(1/2)V}{1.21 \times 10^{-5}}$$

$$V = (2000)(1.21 \times 10^{-5})(2)$$
$$= 2 \times 10^3 (1.21 \times 10^{-5}) 2$$
$$= 4(1.21)(10^{-2}) = 0.04(1.21)\ Ft/sec$$ LAMINAR

IF 1/2" PIPE WITH 0.5 Ft/sec TRAVELS 1000 Ft USING DARCY WEISBACH'S EQUATION WHAT IS THE head loss?

FIRST DETERMINE IS IT LAMINAR OR TURBULENT.

$D = 1/2" = 1/24$ Ft
$V = 0.5$ Ft/s
$\nu = 1.21 \times 10^{-5}$ Ft²/s

$$Re = \frac{DV}{\nu} = \frac{(1/2"/12)(0.5 \text{ Ft/sec})}{1.21 \times 10^{-5} \text{ Ft}^2/\text{s}} = 1722 < 2000$$

$Re < 2000$ LAMINAR

$$\therefore (f) = \frac{64}{Re} = 0.0372$$

$$h_f = \text{DARCY WEISBACH} = \frac{fLV^2}{2gD} = \frac{0.0372\,(1000 \text{ Ft})(0.5)^2 (\text{Ft/sec})^2}{2(32.2 \text{ Ft/sec}^2)(0.048 \text{ Ft})}$$

$(1/24$ Ft$)$

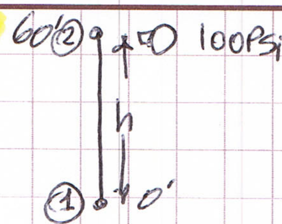
$h_f = 3.01$ Ft VERIFY

Absolute Consulting Engineers
Total Design and R&D Engineers
(949) 852-8700
Absoluteco.Com

REVISIONS

DATE: ______ SHEET: ______
PROJECT: ______
SUBJECT: HEAD
RE: ______

DETAILS — CIVIL . STRUCTURAL . ELECTRICAL . MECHANICAL . PLUMBING . ENERGY . LEED . GREEN — ENGINEERING & CONSULTING



PIPE IS 2" COPPER
IF PUMP READS 100PSI
& 60' FT ABOVE F.F.
WHAT IS READING @ POINT 2

$$\text{Pump} + Z_1 + d_1 + \frac{V^2}{2} = Z_2 + d_2 + \frac{V^2}{2} + h_f$$

(① ② ③ ④ ⑤ ⑥)

$Z_1 = 60'$

$\text{Pump} = 100\text{Psi}$

⑥ h_f = ALL MINOR LOSSES IGNORED

(3,4,5) = COMBINED ENERGY = E_2

①,② = ASSUME PART of PUMP ENERGY & (100Psi) OR ZERO & PUMP IS 100Psi

$E_2 = 100\text{Psi} + 60\,(0.43) =$ 125.97 Psi

Absolute Consulting Engineers
Total Design and R&D Engineers
(949) 852-8700
Absoluteco.Com

REVISIONS
△
△

DATE: ______ SHEET: ______
PROJECT: ______
SUBJECT: FIRE SPRINKLER
RE: ______

DETAILS — CIVIL . STRUCTURAL . ELECTRICAL . MECHANICAL . PLUMBING . ENERGY . LEED . GREEN — ENGINEERING & CONSULTING

SPRINKLER HEAD WITH K=7.6 FLOW COEFFICIENT WITH 15 PSI HEAD PRESSURE
Q, FLOW IS ?

$$Q = K\sqrt{h, psi}$$

$$= 7.6\sqrt{15}$$

$$= 29.43 \text{ GPM}$$

Absolute Consulting Engineers
Total Design and R&D Engineers
(949) 852-8700
Absoluteco.Com

REVISIONS

DATE: SHEET:
PROJECT:
SUBJECT: $Q = mc\Delta T$
RE:

DETAILS | CIVIL . STRUCTURAL . ELECTRICAL . MECHANICAL . PLUMBING . ENERGY . LEED . GREEN | ENGINEERING & CONSULTING

HOT WATER NEEDED: 500 GALLONS FROM 50°F → 110°F

$Q = mc\Delta T$

$= 500$ GALLONS $8.33\ (110° - 50°F)$

$= 249{,}900$ BTU

$= 249{,}900$ BTU$/3.412 = 73.24 \times 10^3 = 73.24$ KW

500 GALLONS 40°F to 120°F

$Q = 500(8.33)(120 - 40)$

$= 333{,}200$ BTU

Absolute Consulting Engineers
Total Design and R&D Engineers
(949) 852-8700
Absoluteco.Com

REVISIONS

DATE: SHEET:
PROJECT:
SUBJECT:
RE:

DETAILS CIVIL . STRUCTURAL . ELECTRICAL . MECHANICAL . PLUMBING . ENERGY . LEED . GREEN ENGINEERING & CONSULTING

COLORS OF PIPES

COPPER TYPE K = GREEN
L = BLUE
M = RED
(?) ← DRAIN WASTE VENT = ? YELLOW

↑ THICK
?

AFFINITY

WHAT HP IS REQUIRED TO INCREASE 1750 RPM @ 50 HP TO 3500 RPM?

AFFINITY LAWS

$$\frac{Q_1}{Q_2} = \frac{N_1}{N_2} = \frac{D_1}{D_2}$$

$$\frac{HP_1}{HP_2} = \left(\frac{D_1}{D_2}\right)^3 = \left(\frac{N_1}{N_2}\right)^3$$

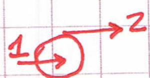
$$\frac{H_1}{H_2} = \left(\frac{N_1}{N_2}\right)^2 = \left(\frac{D_1}{D_2}\right)^2$$

$$\frac{HP_1}{HP_2} = \left(\frac{N_1}{N_2}\right)^3$$

$$\frac{50}{HP_2} = \left(\frac{1750}{3500}\right)^3 = 0.125 = \frac{1}{8}$$

$HP_2 = (50)(8) =$ 400 HP

PUMPS



ADD ENERGY TO MOVE FLUID

$E_{ADDED} = E_{t,2} - E_{t,1}$

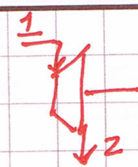
$E_A/g = h_A$

$E_A = (1000\ W/KW)(KW\ INPUT)\,\eta_{PUMP} / \dot{m}$

$E_A = \dfrac{(550\ Ft\text{-}lbf/sec\text{-}hp)(HP_{INPUT})\,\eta_{PUMP}}{\dot{m}}$

WHP (WATER H.P.) = HYDRAULIC H.P.
= THEORETICAL H.P.
$= (HP_{INPUT})\,\eta_{PUMP}$

TURBINES



E_t = TOTAL ENERGY

ENERG REMOVED FROM A MOVING FLUID

$E_{EXTRACTED} = E_{t,1} - E_{t,2}$

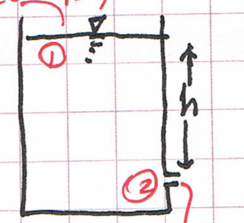
Absolute Consulting Engineers
Total Design and R&D Engineers
(949) 852-8700
Absoluteco.Com

REVISIONS △ △

DATE: ______ SHEET: ______
PROJECT: ______
SUBJECT: ______
RE: ______

DETAILS — CIVIL . STRUCTURAL . ELECTRICAL . MECHANICAL . PLUMBING . ENERGY . LEED . GREEN — ENGINEERING & CONSULTING

DISCHARGE FROM TANK



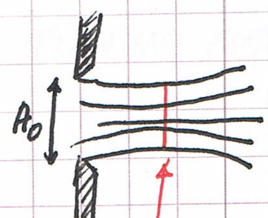
$$z_1 = z_2 + \frac{V^2}{2g} \rightarrow z_2 - z_1 = -\frac{V^2}{2g}$$

$$V_t = \sqrt{2gh} = \left((z_2 - z_1)2g\right)^{1/2}$$

$$V_o = C_v\sqrt{2gh} \quad ; \quad C_v = \frac{\text{ACTUAL VELOCITY}}{\text{THEORETICAL VELOCITY}} = \frac{V_o}{V_t}$$

E_f = ORIFICE ENERGY LOSS $= \left(\frac{1}{C_v^2} - 1\right)\frac{V_o^2}{2} = (1 - C_v^2)gh$

$h_{effective} = C_v^2 h$; TOTAL HEAD PRODUCING DISCHARGE



$A_{VENA\ CONTRACTA} = C_c A_{ORIFICE}$

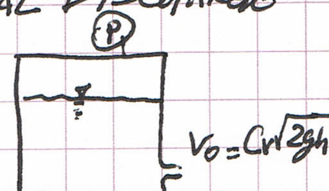
$C_c = A_{v.c.} / A_o$

THEORY: DISCHARGE RATE $= \dot{V} = C_d V_t A_o = C_d A_o \sqrt{2gh}$

C_d = ACTUAL DISCHARGE / THEORETICAL DISCHARGE

- IF TANK HAS EXTERNAL PRESSURE, P_2

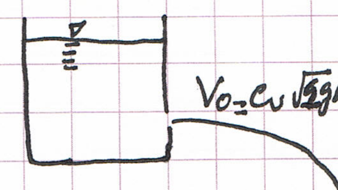
$$h = z_1 - z_2 + \frac{P}{\rho g}$$



- FLUID STREAM

$$V_x = V_o$$

$$x = V_o t = 2C_v\sqrt{hy} = V_o\sqrt{2y/g}$$

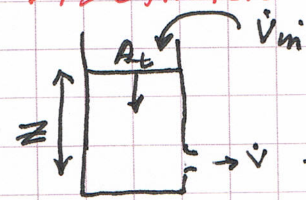


$$V_y = gt$$

$$y = gt^2 = \frac{gx^2}{2V_o^2} = \frac{x^2}{4hC_v^2}$$

ORIFICE DISCHARGE

. TIME TO EMPTY FROM TANK



$\rightarrow \dot{V} = C_d A_o \sqrt{2gz}$

VOLUME = $\dot{V}dt$ = FLOW RATE
(GPM)(min) = → OUT

VOLUME = $-A_{tank}\,dZ$ = FLOW RATE LEAVING = in

$$\dot{V}dt = -A_t dZ$$

$$C_d A_o \sqrt{2gz}\, dt =$$

$$t = \int_{Z_1}^{Z_2} -A_t dZ \Big/ \left(C_d A_o \sqrt{2gz}\right) = \frac{2A_t\left(\sqrt{Z_1} - \sqrt{Z_2}\right)}{C_d A_o \sqrt{2g}}$$

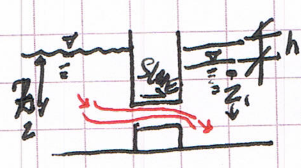
if TANK IS NOW FED BY A SEPARATE SOURCE

$$t_{REPLENISHED} = \int_{Z_1}^{Z_2} A_t dZ \Big/ \left(C_d A_o \sqrt{2gz} - \dot{V}_{in}\right)$$

- CORRECTIONS TO ORIFICE DISCHARGE
  CORRECTIONS ARE ADDED to C_d
  To CORRECT REDUCE ORIFICE SIZE

✓ HIGER VELOCITY FOR LARGE OPENINGS

- CULVERT

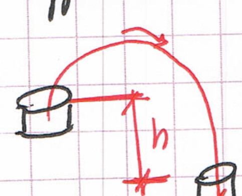


WATER CONDUIT TO OVERCOME AN OBSTRUCTION.

TORECELLI'S EQUATION DOES NOT APPLY FOR PARTIAL FLOW Therefore CULVERT MAY NOT APPLY. HOWEVER, if full $V_0 = C_d A \sqrt{2gh}$

$h_{effective} = h - h_f$ (FRICTION WITHIN BARREL, 50→60 FT LONG) $- h_{minor}$ (ENTRANCE, EXIT)

- SIPHON



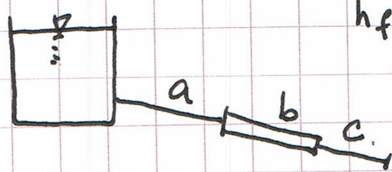
BENT TUBE CARRYING FLUID

$\dot{V} = C_d A V = C_d A \sqrt{2gh}$

very LITTLE KNOWN

PIPE NETWORK

- SERIES

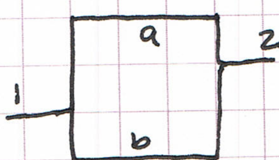


$h_{f\,TOTAL} = h_{f,a} + h_{f,b} + h_{f,c}$

$\dot m_1 = \dot m_a = \dot m_b = \dot m_c$

$A_aV_a = A_bV_b = A_cV_c$

- PARALLEL



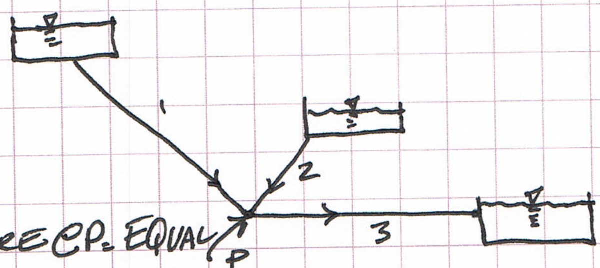
$\dot m_1 = \dot m_2 \Rightarrow A_1V_1 = A_2V_2 = A_aV_a + A_bV_b$

$h_{f,a} = h_{f,b} = h_{f\,1\to2}$

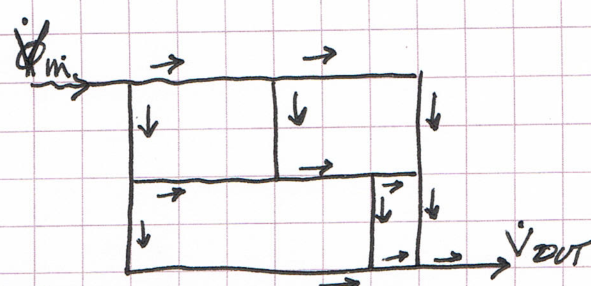
- RESERVOIR

$\dot m_1 + \dot m_2 = \dot m_3$

TOTAL PRESSURE @P EQUAL



- HARDY CROSS METHOD
  LOOP METHOD
  - ALL PRESSURES ARE SAME @ JUNCTIONS
  - VOLUME FLOW RATES PER CONTINUITY EQUATIONS
  - NUMERICAL METHODS & TRIAL & ERROR



Absolute Consulting Engineers
Total Design and R&D Engineers
(949) 852-8700
Absoluteco.Com

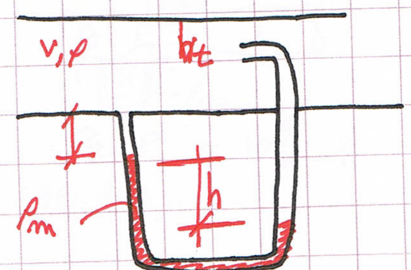
REVISIONS

DATE: ______ SHEET: ______
PROJECT: ______
SUBJECT: ______

RE: [redacted]

DETAILS — CIVIL . STRUCTURAL . ELECTRICAL . MECHANICAL . PLUMBING . ENERGY . LEED . GREEN — ENGINEERING & CONSULTING

PITOT _ STATIC



$P_{TOTAL} = P_{STATIC} + \text{VELOCITY HEAD}$

$$\frac{V^2}{2} = hg = \frac{P_t - P_s}{\rho} \Rightarrow V = \sqrt{2gh}$$

GAGE w/ ρ_m

$$\frac{V^2}{2} = \frac{P_t - P_s}{\rho} = h(\rho_m - \rho)g/\rho \Rightarrow V_m = \left[2gh\left(\frac{\rho_m - \rho}{\rho}\right)\right]^{1/2}$$

CORRECTION

$V = C_I V_m$ (measured)

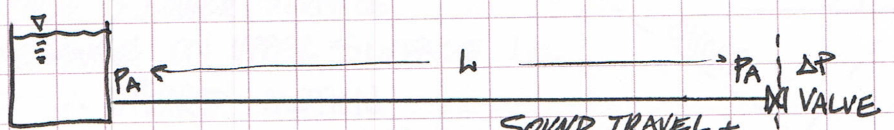
($C_I \cong 1.0$) COEFFICIENT of INSTRUMENT

USE LAMINAR FLOW VALUES $V_{MAX} = \frac{2}{3} V_{ave}$
if TUBE IS PLACED @ CENTER & $Re < 2100$

WATER HAMMER

SUDDEN INCREASE IN PRESSURE BY REDUCTION IN VELOCITY

- CAUSE: SUDDEN VALVE CLOSING
- RIGID PIPE OR ELASTIC PIPE HAVE TWO ALTERNATE METHODS



$t = L/a$ SOUND TRAVEL + TIME TO PUT TO REST

a = VELOCITY of SOUND IN MEDIUM

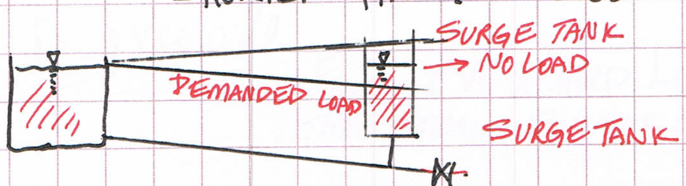
RAREFACTION: WAVE (@ PRESSURE of WATER SOURCE) WITH VELOCITY a BACK TO VALVE

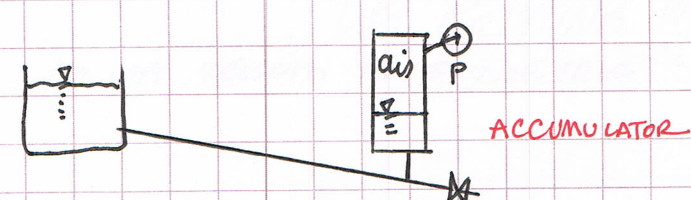
t_1 ⟵ ⟶ t_2 $t = 2L/a$

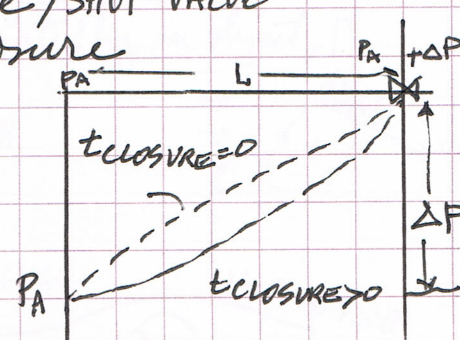
FLUID PRESSURE INCREASE $\Delta P = \rho a \Delta V$ ΔV = DECREASE IN VELOCITY

PRESSURE INCREASE is $\propto \Delta V$ NOT TIME TO close valve
"INSTANTANEOUS" vs "RAPID" vs "SUDDEN" IS ONLY RAPID

IF PIPE "L" IS LONG, BY THE TIME WAVE ARRIVES, VALVE IS closed.
IF PIPE IS SHORT. DIFFICULT to close/SHUT VALVE
SHORTER PIPE : SLOWER closure







WATER HAMMER

PRESSURES ARE ABSORBED AT TANK OR ACCUMULATORS
PIPE ELASTICITY : EFFECT on a

$E_{combined\ bulk}$ = $E_{water}\, t_{pipe}\, E_{pipe} / (t_{pipe} E_{pipe} + D_{pipe} E_{water})$
MODULUS of ELASTICITY

HAZEN WILLIAMS

- ADVANTAGE "C" DOES NOT DEPEND ON Re

$$h_f(ft) = \frac{3.022\, V^{1.85} L}{C^{1.85} D^{1.17}} = \frac{10.44\, L\, Q_{gpm}^{1.85}}{C^{1.85}\, d_{inches}^{4.87}}$$

$Re \gg 2100$
$T = 60°F$

C = 140 (NEW WATER PIPE); C = 100 (OLD PIPE)
C = 20% TO 40% LOWER THAN WATER

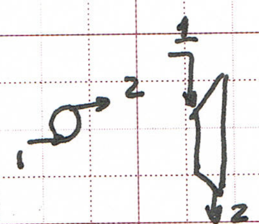
- LENGTH = TRUE + ADDED (VALVES, ETC).

= HYDRAULIC DEVELOPED LENGTH

- VALVE FLOW COEFFICIENT. $C_V = \frac{Q_{gpm}}{\sqrt{\frac{\Delta P_{psi}}{SG}}} = \frac{29.9\, d_{in}^2}{\sqrt{K}}$

K = Loss Coefficient ; $f L_e = KD$

- PUMPS & TURBINES

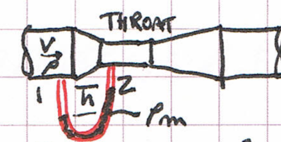


$$E_A = E_{t2} - E_{t1}$$

$$h_A = \frac{E_A}{g} = \frac{E_A\, g_c}{g}$$

$$E_A = \frac{1000 \frac{W}{KW} (P_{KW,\,INPUT})\, \eta_{PUMP}}{\dot m} = \frac{\left(550 \frac{ft\text{-}lb_f}{sec\, hp}\right) P_{HP,\,INPUT}\, \eta_{PUMP}}{\dot m}$$

VENTURI METER



$$\frac{V_1^2}{2} + \frac{P_1}{\rho} = \frac{V_2^2}{2} + \frac{P_2}{\rho} \quad \& \; A_1V_1 = A_2V_2$$

$P_2 - P_1 \approx 10\%$?

$$V_2 = \frac{C_v \text{ CORRECTION}}{\sqrt{1-\left(\frac{A_2}{A_1}\right)^2}} \sqrt{\frac{2(P_1-P_2)}{\rho}}$$

$C_v \approx 1.0 \; (0.98, 0.99)$

if $\beta = \frac{D_2}{D_1}$ & F_{VA} (VELOCITY of APPROACH FACTOR) $= 1\Big/\sqrt{\left(1-\left(\frac{A_2}{A_1}\right)^2\right)}$

Beta Ratio $= 1\Big/\sqrt{1-\beta^4}$

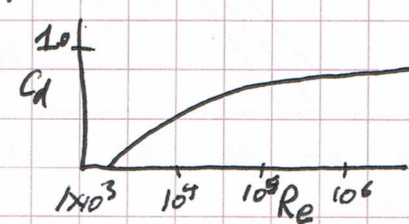
$$V_2 = C_v F_{VA} \sqrt{2(P_1-P_2)/\rho} \qquad (\Delta P = \rho g h)$$

MEASURING $h \rightarrow V_2 = C_v F_{VA} \sqrt{2g\left(\frac{\rho_m - \rho}{\rho}\right)h}$

FLOWRATE $\quad \dot{V} = C_d F_{VA} A_2 V_{2\,IDEAL} \qquad C_d \approx 0.95$ TURBULENT

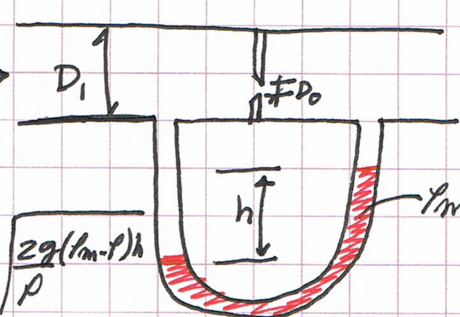
$$C_f = C_d F_{VA} = C_d\Big/\sqrt{(1-\beta^4)}$$

$$\dot{V} = C_f A_2 \sqrt{2g\frac{(\rho_m-\rho)h}{\rho}}$$



ORIFICE METER

- MEASURE FLOW RATE IN SMALL PIPES



$$A_2 = \frac{\pi D_2^2}{4} = C_c \frac{\pi D_o^2}{4} = C_c A_o$$

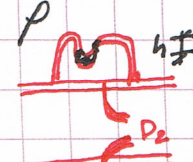
$$V_o = \frac{C_v}{\left(1-\left(\frac{C_c A_o}{A_1}\right)^2\right)^{1/2}} \sqrt{\frac{2(P_1-P_2)}{\rho}} = \frac{C_v}{\sqrt{1-\left(\frac{C_c A_o}{A_1}\right)^2}} \sqrt{\frac{2g(\rho_m-\rho)h}{\rho}}$$

$C_d \approx 0.55 \rightarrow 0.75$ (USUALLY $0.60 \rightarrow 0.65$)

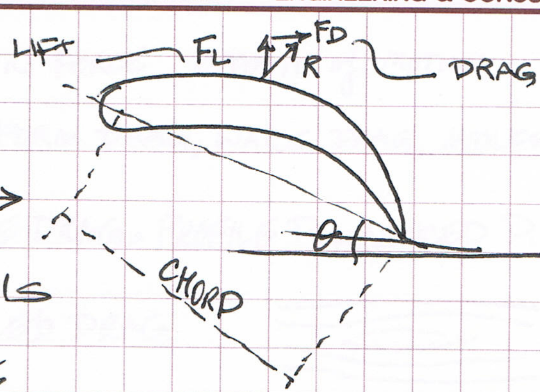
$$\dot{V} = C_f A_o \sqrt{\frac{2g}{\rho}(\rho_m - \rho)h}$$

$$C_f = C_d F_{VA} = C_d \sqrt{\left(1-\left(\frac{C_c A_o}{A_1}\right)^2\right)}$$

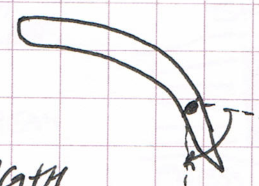
FLOW NOZZLE



LIFT



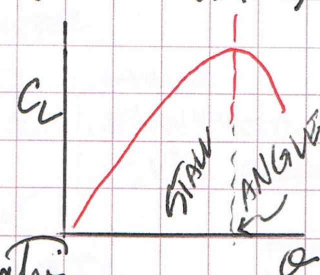
- UPWARD FORCE ON OBJECTS
- UPPER SURFACE > LOWER SURFACE
- STATIC PRESSURE ON UPPER SURFACE IS REDUCED ∴ UPWARD MOTION
- @ LOWER SPEED INCREASE CURVATURE
- FLAPS ADDED ARE USED @ LOWER SPEED TAKE OFF OR LANDING



$F_L = C_L A \rho V^2 / 2$

SPAN = WING LENGTH
CHORD LENGTH RATIO = SPAN/CHORD
AREA ≐ CHOR * SPAN (RECTANGULAR)

C_L = EFFECTIVENESS COEF. of LIFT
$= f(\text{SHAPE}, Re)$ = THEORETICAL $= 2\pi(\sin\theta)$



INCREASE θ TILL YOU HAVE STALL

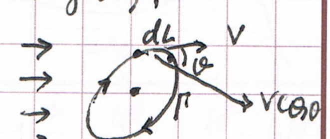
CIRCULATION

concept of calculating LIFT generated by an object, Γ

$\Gamma = \oint V \cos\theta \, dl$

$F_{LIFT} = \rho V \Gamma \times$ CHORD LENGTH

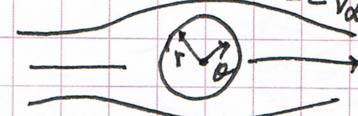
- THEORETICAL FOUNDATION



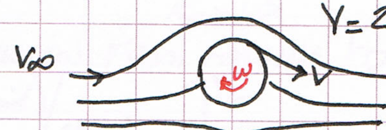
LIFT ROTATING CYLINDER

NO LIFT VELOCITY IS SYMMETRIC

$V = 2 V_\infty \sin\theta$



KUTTA JOUKOWSKY THEORM OR MAGNUS EFFECT



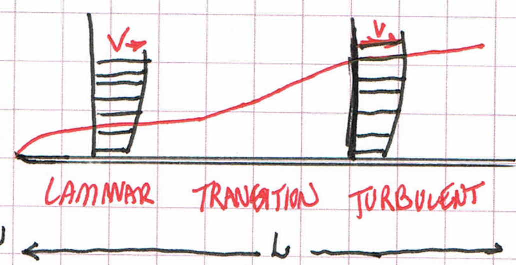
$V = 2V_\infty \sin\theta + \frac{\Gamma}{2\pi r}$

$F_{\Gamma LIFT}$ PER UNIT LENGTH $= \rho V_\infty \Gamma$ NOT very efficient

$\Gamma = 2\pi r^2 \omega$, NO SLIP, IDEAL Case MAX. LIFT = 4π

FLOW OVER PARALLE FLAT PLATES

PRANDEL'S BOUNDARY LAYER THEORY



C_f = SKIN FRICTION COEFFICIENT

LAMINAR = SMOOTH, FLAT PLATE BLASIUS SOLUTION

Re CRITICAL for LAMINAR flow = 530,000

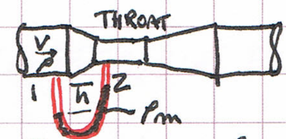
HOWEVER TRANSITION can Be 100,000 → 1,000,000 $C_f = 1.328/\sqrt{Re}$

TURBULENT FLOW $C_f = 0.455/(\log Re)^{2.58}$

$F_D = 2 \; C_f \rho A V^2/2 = C_f \rho A V^2$

← Both SIDE of PLATE (the 2)

VENTURI METER



$$\frac{V_1^2}{2} + \frac{P_1}{\rho} = \frac{V_2^2}{2} + \frac{P_2}{\rho} \quad \& \; A_1V_1 = A_2V_2$$

$P_2 - P_1 \approx 10\%$?

$$V_2 = \frac{C_v \text{ CORRECTION}}{\sqrt{1-\left(\frac{A_2}{A_1}\right)^2}} \sqrt{\frac{2(P_1-P_2)}{\rho}}$$

$C_v \approx 1.0$ (0.98, 0.99)

if $\beta = \frac{D_2}{D_1}$ Beta Ratio & F_{VA} (VELOCITY of APPROACH FACTOR) $= 1 \Big/ \sqrt{\left(1-\left(\frac{A_2}{A_1}\right)^2\right)}$

$$= 1 \Big/ \sqrt{1-\beta^4}$$

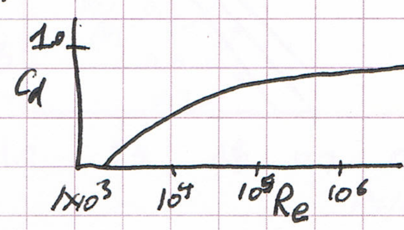
$$V_2 = C_v F_{VA} \sqrt{2(P_1-P_2)/\rho} \qquad (\Delta P = \rho g h)$$

MEASURING $h \rightarrow V_2 = C_v F_{VA} \sqrt{2g\left(\frac{\rho_m-\rho}{\rho}\right)h}$

FLOWRATE $\dot{V} = C_d F_{VA} A_2 V_{2\,IDEAL}$ $\quad C_d \approx 0.95$ TURBULENT

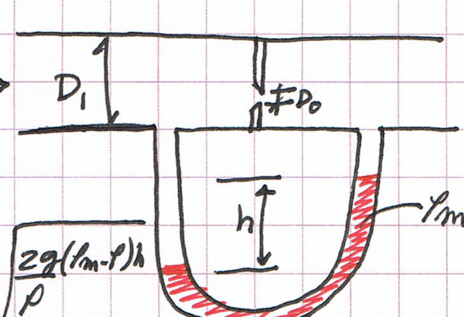
$$C_f = C_d F_{VA} = C_d \Big/ \sqrt{(1-\beta^4)}$$

$$\dot{V} = C_f A_2 \sqrt{2g\frac{(\rho_m-\rho)h}{\rho}}$$



ORIFICE METER

- MEASURE FLOW RATE IN SMALL PIPES



$$A_2 = \frac{\pi D_2^2}{4} = C_c \frac{\pi D_o^2}{4} = C_c A_o$$

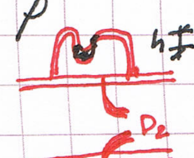
$$V_o = \frac{C_v}{\left(1-\left(\frac{C_cA_o}{A_1}\right)^2\right)^{1/2}} \sqrt{\frac{2(P_1-P_2)}{\rho}} = \frac{C_v}{\sqrt{1-\left(\frac{C_cA_o}{A_1}\right)^2}} \sqrt{\frac{2g(\rho_m-\rho)h}{\rho}}$$

$C_d \approx 0.55 \rightarrow 0.75$ (USUALLY $0.60 \rightarrow 0.61$)

$$\dot{V} = C_f A_o \sqrt{\frac{2g(\rho_m-\rho)h}{\rho}}$$

$$C_f = C_d F_{VA} = C_d \Big/ \sqrt{\left(1-\left(\frac{C_cA_o}{A_1}\right)^2\right)}$$

FLOW NOZZLE



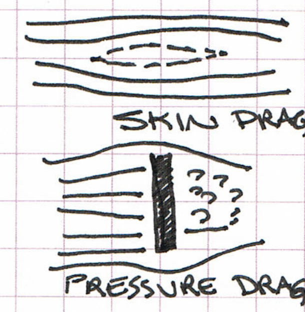
DRAG

FRICTION FORCE OPPOSIT of MOTION

PROFILE, SKIN FRICTION, PRESSURE DRAG, FORM DRAG, WAKE DRAG, INDUCED D.

TOTAL DRAG = SKIN FRICTION + PRESSURE DRAG = PROFILE D. + INDUCED D.

PRESSURE DRAG = WAKE DRAG + INDUCED DRAG



F_D TOTAL DRAG $= C_D A \rho V^2/2$ C_D = DRAG COEF.

A = PROJECTED AREA, FRONTAL AREA

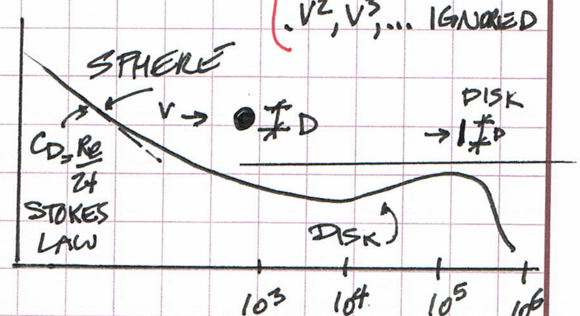
= IN AIRFOIL, FLAT PLATES; AREA IS parallel to STREAM

SPHERES & DISKS: f(Re @ LAMINAR) = ENTIRELY SKIN FRICTION @ LAMINAR

$Re \leq 0.4$ $C_D = 24/Re$ SPHERE or DISK DIAMETER

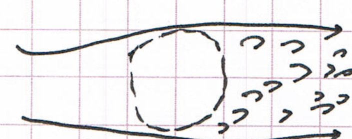
$F_D = C_D A \rho V^2/2 = \frac{24}{Re} A \rho V^2/2 = 3\pi\mu VD$ STOKE'S LAW

- LAMINAR
- NEWTON VISCOSITY = VALID
- $V^2, V^3, \ldots$ IGNORED

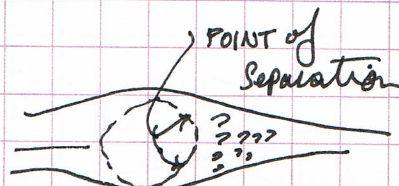


DISK: NO SURFACE
DRAG COEF. IS BASE DUE to WAKE

SPHERE: SHARP REDUCTION IN $10^5 = Re$
PRIMARILY BASED ON WAKE
IN CREATING Smooth SURFACE, DRAG REDUCES



$Re < 10^5$



$Re > 10^5$

TERMINAL VELOCITY: FLOATING FORCE (minimum) FROM FALLING $F_D = mg - F_b$ (BOUYANT)

$$V = \left[2(mg - F_b)/C_D A \rho_{FLUID}\right]^{1/2} = \left[2Vg(\rho_{obj} - \rho_{fluid})/C_D A \rho_{FLUID}\right]^{1/2}$$

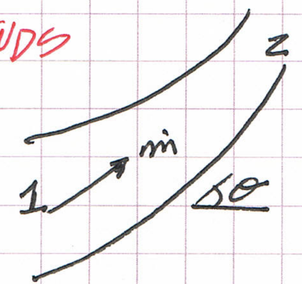
$$V\Big|_{SPHERE, D} = \sqrt{2Dg(\rho_{SPHERE} - \rho_{FLUID})/3C_D \rho_{FLUID}}$$

SMALL SPHERICAL, STOKE'S LAW $V = D^2 g(\rho_{SPHERE} - \rho_{FLUID})/18\mu$

CONFINED STREAM IN PIPE BENDS

$$F_x = P_2 A_2 \cos\theta - P_1 A_1 + \dot{m}(V_2 \cos\theta - V_1)$$

$$F_y = (P_2 A_2 + \dot{m} V_2) \sin\theta$$



Absolute Consulting Engineers
Total Design and R&D Engineers
(949) 852-8700
Absoluteco.Com

REVISIONS

DATE: SHEET:
PROJECT:
SUBJECT:
RE:

DETAILS CIVIL . STRUCTURAL . ELECTRICAL . MECHANICAL . PLUMBING . ENERGY . LEED . GREEN ENGINEERING & CONSULTING

NON SPHERICAL PARTICLES & CYLINDERS

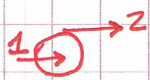
Absolute Consulting Engineers
Total Design and R&D Engineers
(949) 852-8700
Absoluteco.Com

REVISIONS

DATE: ________ SHEET: ________
PROJECT: ________
SUBJECT: ________
RE: ________

DETAILS CIVIL . STRUCTURAL . ELECTRICAL . MECHANICAL . PLUMBING . ENERGY . LEED . GREEN ENGINEERING & CONSULTING

PUMPS



ADD ENERGY TO MOVE FLUID

$E_{ADDED} = E_{t,2} - E_{t,1}$

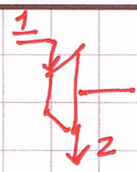
$E_A / g = h_A$

$E_A = (1000\ W/KW)(KW\ INPUT)\ \eta_{PUMP} / \dot{m}$

$E_A = \dfrac{(550\ Ft\text{-}lbf/sec\text{-}hp)(HP_{INPUT})}{\dot{m}}\ \eta_{PUMP}$

WHP (WATER H.P.) = HYDRAULIC H.P.
= THEORETICAL H.P.
$= (HP_{INPUT})\ \eta_{PUMP}$

TURBINES

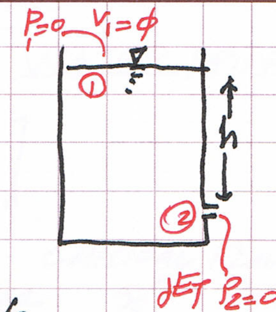


E_t = TOTAL ENERGY

ENERG REMOVED FROM A MOVING FLUID

$E_{EXTRACTED} = E_{t,1} - E_{t,2}$

DISCHARGE FROM TANK



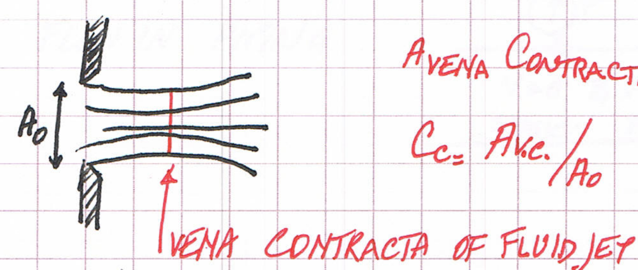
$Z_1 = Z_2 + \frac{V^2}{2g} \rightarrow Z_2 - Z_1 = -\frac{V^2}{2g}$

$V_t = \sqrt{2gh} = \left((Z_2 - Z_1)2g\right)^{1/2}$

$V_o = C_v\sqrt{2gh}$; $C_v = \frac{\text{ACTUAL VELOCITY}}{\text{THEORETICAL VELOCITY}} = \frac{V_o}{V_t}$

E_f = ORIFICE ENERGY LOSS $= \left(\frac{1}{C_v^2} - 1\right)\frac{V_o^2}{2} = (1 - C_v^2)gh$

$h_{effective} = C_v^2 h$; TOTAL HEAD PRODUCING DISCHARGE



$A_{VENA\ CONTRACTA} = C_c A_{ORIFICE}$

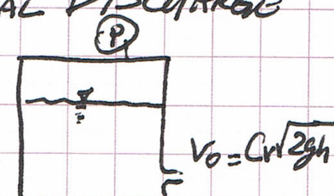
$C_c = A_{v.c.} / A_o$

THEORY: DISCHARGE RATE $= \dot{V} = C_d V_t A_o = C_d A_o\sqrt{2gh}$

C_d = ACTUAL DISCHARGE / THEORETICAL DISCHARGE

- IF TANK HAS EXTERNAL PRESSURE, P_Z

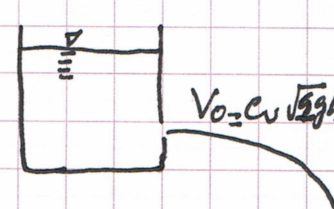
$h = Z_1 - Z_2 + \frac{P}{\rho g}$



- FLUID STREAM

$V_x = V_o$

$x = V_o t = 2C_v\sqrt{hy} = V_o\sqrt{2y/g}$

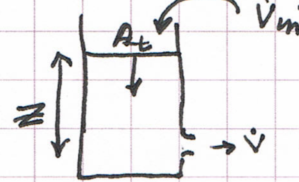


$V_y = gt$

$y = gt^2 = \frac{gx^2}{2V_o^2} = \frac{x^2}{4hC_v^2}$

ORIFICE DISCHARGE

- TIME TO EMPTY FROM TANK



$\rightarrow v = C_d A_0 \sqrt{2gz}$

VOLUME = $\dot{V} dt$ = FLOW RATE
(GPM)(MIN) = → OUT

VOLUME = $-A_{tank} dZ$ = FLOW RATE LEAVING = IN

$$\dot{V} dt = -A_t dZ$$

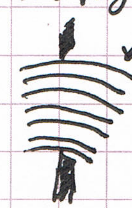
$$C_d A_0 \sqrt{2gz}\, dt =$$

$$t = \int_{z_1}^{z_2} -A_t dZ \Big/ \left(C_d A_0 \sqrt{2gz}\right) = \frac{2A_t\left(\sqrt{z_1} - \sqrt{z_2}\right)}{C_d A_0 \sqrt{2g}}$$

if TANK IS NOW FED BY A SEPARATE SOURCE

$$t_{REPLENISHED} = \int_{z_1}^{z_2} A_t dZ \Big/ \left(C_d A_0 \sqrt{2gz} - \dot{V}_{in}\right)$$

- CORRECTIONS TO ORIFICE DISCHARGE
  CORRECTIONS ARE ADDED TO C_d
  TO CORRECT REDUCE ORIFICE SIZE



HIGER VELOCITY FOR LARGE OPENINGS

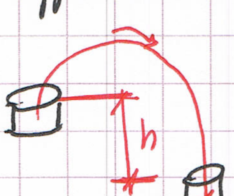
- CULVERT

WATER CONDUIT TO OVERCOME AN OBSTRUCTION.

TORECELLI'S EQUATION DOES NOT APPLY FOR PARTIAL FLOW
Therefore CULVERT MAY NOT APPLY. HOWEVER, if full $V_0 = C_d A\sqrt{2gh}$

$h_{effective} = h - h_f$ (FRICTION WITHIN BARREL, 50→60 ft LONG) $- h_{minor}$ (ENTRANCE, EXIT)

- SIPHON



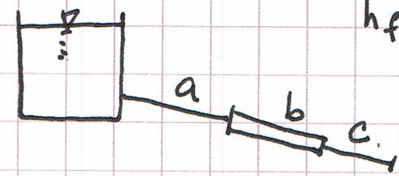
BENT TUBE CARRYING FLUID

$\dot{V} = C_d A V = C_d A \sqrt{2gh}$

very LITTLE KNOWN

PIPE NETWORK

- SERIES

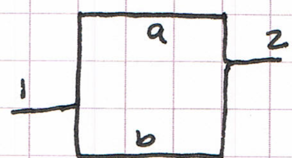


$h_{f\,TOTAL} = h_{f,a} + h_{f,b} + h_{f,c}$

$\dot{m}_1 = \dot{m}_a = \dot{m}_b = \dot{m}_c$

$A_aV_a = A_bV_b = A_cV_c$

- PARALLEL



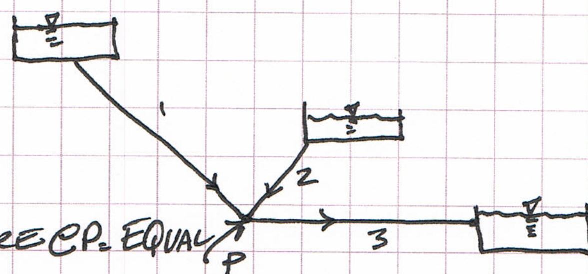
$\dot{m}_1 = \dot{m}_2 \Rightarrow A_1V_1 = A_2V_2 = A_aV_a + A_bV_b$

$h_{f,a} = h_{f,b} = h_{f\,1\to 2}$

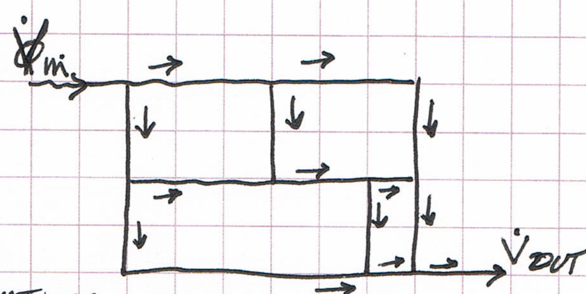
- RESERVOIR

$\dot{m}_1 + \dot{m}_2 = \dot{m}_3$

TOTAL PRESSURE @ P. EQUAL



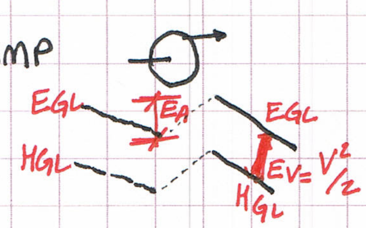
- HARDY CROSS METHOD
  LOOP METHOD
  - ALL PRESSURES ARE SAME @ JUNCTIONS
  - VOLUME FLOW RATES PER CONTINUITY EQUATIONS
  - NUMERICAL METHODS & TRIAL & ERROR



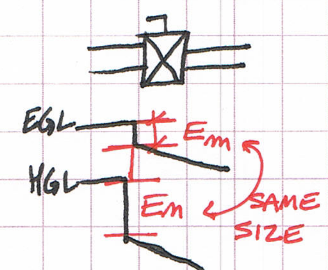
EGL & HGL

- RESERVOIR

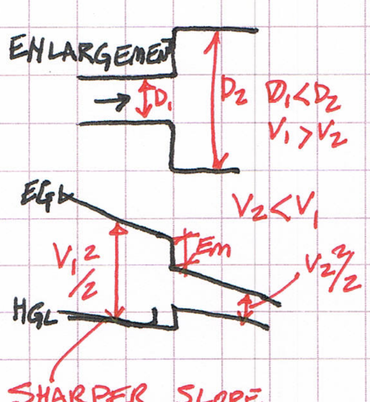
- PUMP



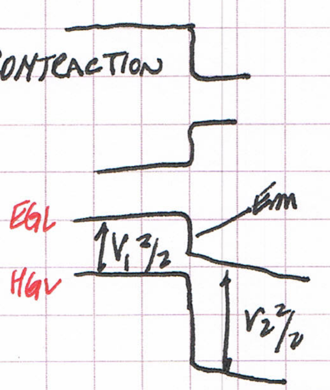
- VALVES, FITTINGS, OBSTRUCTIONS



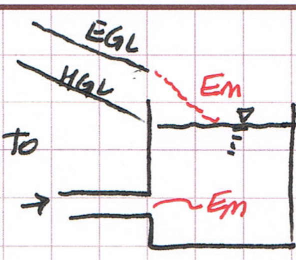
- ENLARGEMENT



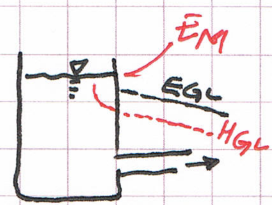
- CONTRACTION



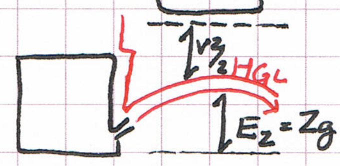
- TRANSITION TO RESERVOIR



- TRANSITION TO PIPELINE



- NOZZLE



Absolute Consulting Engineers
Total Design and R&D Engineers
(949) 852-8700
Absoluteco.Com

REVISIONS

SHEET NUMBER
JOB NAME:
RE:
DATE

DETAILS

ENGINEERING & CONSULTING

IF FLOW RATE IS 150GPM w/ $\mu = 1.5\times10^{-3}$ lb.sec/ft² & $\rho = 1.7$ slug/ft³ & DIAMETER IS 4"; THEN

• DETERMINE Re, FLOW CLASSIFICATION & PRESSURE DROP PER 1000 Ft PIPE

• $Re = \frac{VD}{\nu} = \frac{VD}{\mu/\rho} = \frac{Q/A\ D}{\mu/\rho} = \frac{QD}{\frac{\pi D^2}{4}\mu/\rho} = \frac{4Q\rho}{\pi D \mu}$

$D = 4"/12" = 1/3$ Ft ; $Q = 150\ GPM = (150\,(0.1337\ Ft^3)/MIN)\left(\frac{1 min}{60 sec}\right)$

$\mu = 1.5\times10^{-3}$ lb_sec/ft³ ; $\rho = 1.7$ SLUG/Ft³

• $Re = 1450 < 21{,}000$ ∴ LAMINAR

• HEAD LOSS

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

$f = \frac{64}{Re}$ LAMINAR

$= 64/1450 = 0.04413$

$$h_f = (0.04413)\left(\frac{1000}{(4/12)}\right)\left(\frac{Q}{A}\right)^2\frac{1}{2(32.2)}$$

$$\left(\frac{Q}{A}\right)^2 = \left(\frac{(150)\,0.1337}{60\ \frac{\pi}{4}(4/12)^2}\right)^2$$

$h_f = 30.26$ Ft

$= \frac{\Delta P}{\gamma}$

$\Delta P = \rho g h_f = 30.26\,(1.7)(32.2)$

$= 1656$ Psf

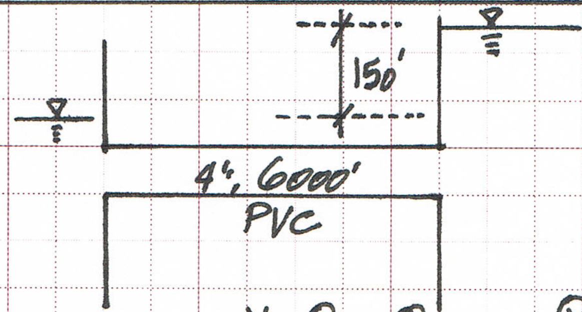
$= \frac{1656}{144} = 11.5$ Psi

IF A 4" PVC PIPE 6000 Ft LONG IS TO TRANSFER H_2O @ 68°F BETWEEN 2 RESEVOIRS WITH 150 Ft SURFACE ELEVATION DIFFERENCE.

FIND FLOW RATE Q?

$$\frac{V_1^2}{2g} + Z_1 + \frac{P_1}{\gamma_1} \pm W = \frac{V_2^2}{2g} + Z_2 + \frac{P_2}{\gamma} + h_f$$

V_1 & $V_2 = \phi$; $\frac{P_1}{\gamma_1} = \frac{P_2}{\gamma_2} \Rightarrow Z_1 = Z_2 + h_f$



$$150 = h_f$$

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

$$= f \frac{6000}{4/12} \frac{V^2}{2(32.2)}$$

$$= f \frac{6000}{0.333} \frac{1}{64.4} \frac{Q^2}{0.0873}$$

$$V = \frac{Q}{A} = \frac{Q}{\frac{\pi}{4}(4/12)^2} = \frac{Q}{0.0873\ ft^2}$$

$$Re = \frac{VD}{\nu} = \frac{Q}{A}\frac{D}{\nu} = \frac{Q}{0.0873} \frac{0.333}{1.217\times10^{-5}} = 3.14\times10^5 Q$$

(1) $Re = 3.14\times10^5 Q$

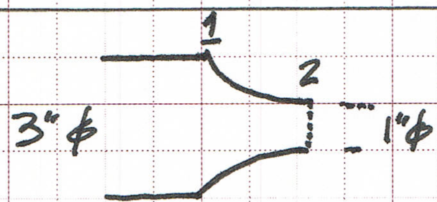
(2) $fQ^2 = 0.00409$

Q	Re	f	fQ		
0.50	1.57×10^5	0.0165	0.004125	≠	0.00409
0.49	1.5386×10^5	0.0165	0.00396	≠	0.00409
0.496	1.557×10^5	0.0165	0.00406	≈	0.00409

∴ $Q = 0.496\ ft^3/sec$

GIVEN FOLLOWING DIAGRAM, FLUID S.P.G. = 0.85, & $P_1 = 100$ PSi
NEGLECT OTHER LOSSES

a. FIND FLOW RATE
b. FIND FORCE EXERTED BY NOZZLE ON PIPE



$$\frac{V_1^2}{2g} + Z_1 + \frac{P_1}{\gamma_1} \pm W = \frac{V_2^2}{2g} + Z_2 + \frac{P_2}{\gamma_2} + h_f$$

$$\rho_1 A_1 V_1 = \rho_2 A_2 V_2$$

- $$\rho_1 A_1 V_1 = \rho_2 A_2 V_2 \qquad \rho_1 = \rho_2$$

$$A_1 V_1 = A_2 V_2$$

$$\pi \frac{D_1^2}{4} V_1 = \pi \frac{D_2^2}{4} V_2$$

$$D_1^2 V_1 = D_2^2 V_2 \rightarrow 9 V_1 = V_2$$

- $$\frac{P_1}{\gamma} + Z_1 + \frac{V_1^2}{2g} = \frac{P_2}{\gamma} + Z_2 + \frac{V_2^2}{2g} \qquad Z_1 = Z_2 \,;\; P_2 = 0 \text{ AMBIENT}$$

$$\frac{(100\text{ Psi})\,144\ \text{in}^2/\text{ft}^2}{(0.85)\,62.4\ \frac{\text{lb}}{\text{ft}^2}} + \frac{V_1^2}{2g} = \phi + \frac{V_2^2}{2g} = \frac{81 V_1^2}{2g}$$

$V_1 = 14.8$ FPS $\qquad V_2 = 133$ fps $\qquad$ ∉

$$Q = A_1 V_1 = \frac{\pi}{4}\left(\frac{3}{12}\right)^2 14.8 = \underline{\underline{0.73\ \text{Ft}^3/\text{s}}}$$

- MOMENTUM EQUATION

$$P_1 A_1 - P_2 A_2 - F = \rho Q (V_2 - V_1)$$

$$14400\ \frac{\pi}{4}\left(\frac{3}{12}\right)^2 - \phi - F = \frac{\gamma}{g}\, 0.73\,(133 - 14.8) \;;\; \frac{\gamma}{g} = 0.85\left(\frac{62.4}{32.2}\right)$$

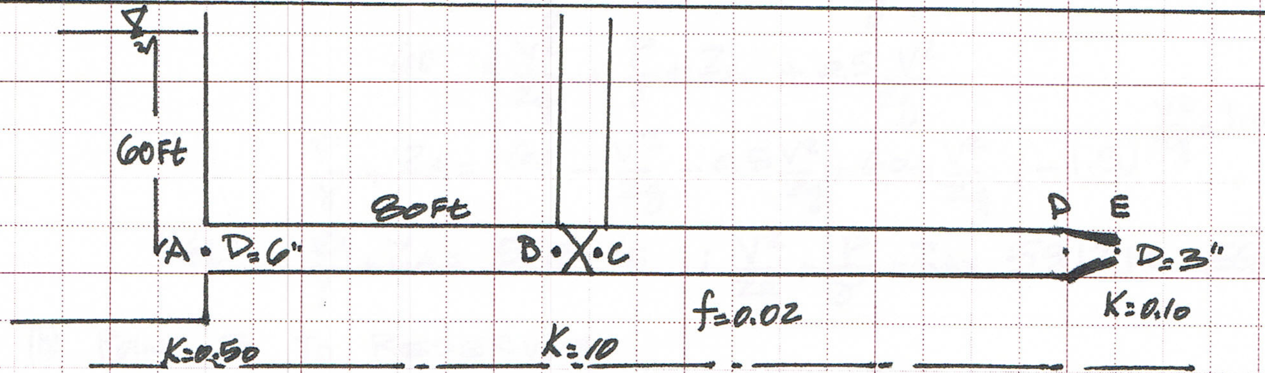
$$\underline{F = 564\ \text{lb}_f}$$

REVISIONS

SHEET NUMBER
JOB NAME:
RE:
DATE

DETAILS ENGINEERING & CONSULTING

DETERMINE THE ELEVATION OF THE HYDRAULIC GRADE LINE (HGL) & THE ENERGY GRADE LINE (EGL) AT POINTS A, B, C, D, & E



SYSTEM: RESERVOIR FREE SURFACE, SQUARED EDGE ENTRANCE, 200 Ft, VALVE, PIPE

SOLVE: HGL & EGL, $V^2/2g$ & $\frac{P}{\gamma} + Z$

RESERVOIR TO NOZZLE:

$$\frac{V_R^2}{2g} + \frac{P_R}{\gamma} + Z_R = \frac{V_E^2}{2g} + \frac{P_E}{\gamma} + Z_E + h_f + h_{minor}$$

$V_R = \phi$; $Z_R - Z_E = 60'$; $\frac{P_R}{\gamma} = \phi$ (atm.); $P_E = \phi$ (ATM)

$h_f = f \frac{L}{D} \frac{V^2}{2g} = 0.02 \frac{200}{6/12} \frac{V^2}{2g}$; MINOR LOSSES $= K\frac{V^2}{2g} = (5+10)\frac{V^2}{2g}$

NOZZLE $= 0.10 \frac{V_E^2}{2g}$

- $0 + 0 + 60 = \frac{V_E^2}{2g} + 0.02 \frac{200}{6/12} \frac{V^2}{2g} + 15\frac{V^2}{2g} + 0.10 \frac{V_E^2}{2g}$
- $A_E V_E = AV \Rightarrow \left(\frac{3}{12}\right)^2 \frac{\pi}{4} V_E = \left(\frac{6}{12}\right)^2 \frac{\pi}{4} V^2 \rightarrow V_E = 4V$
- $60 = \frac{16V^2}{2g} + \frac{0.5V^2}{2g} + 8\frac{V^2}{2g} + 10\frac{V^2}{2g} + 0.10 \frac{16V^2}{2g} \Rightarrow \frac{V^2}{2g} = 1.66 ft$

SLOPE OF HGL = HYDRAULIC GRADIENT

SLOPE OF EGL = ENERGY GRADIENT

Absolute Consulting Engineers
Total Design and R&D Engineers
(949) 852-8700
Absoluteco.Com

REVISIONS

SHEET NUMBER 1/
JOB NAME: HYDRAULICS
RE: EQ. LENGTH
DATE 3/30/05

DETAILS

ENGINEERING & CONSULTING

GRAVITY FLOW BETWEEN TWO RESEVOIR W/ 250 Ft, 2" ϕ STEEL PIPE (SCREWED FITTINGS), 7 REGULAR 90° ELBOWS, 16 COUPLES, 4 UNIONS, 5 FLOW THROUGH LINE TEES, & 2 gate VALVES. WHAT IS EQUIVALENT LENGTH OF PIPE

FITTINGS	QUANTITY		UNIT FITTING (Ft)		TOTAL EQ. L. (Ft)
90 ELLS	7	*	8.5	=	59.5
COUPLE	16	*	0.45	=	7.2
UNION	4	*	0.45	=	1.8
Tee	5	*	7.7	=	38.5
VALVE	2	*	1.5	=	3.0
					110 Ft

$L_{eq.} = L_{NORMAL} + \Sigma L_{f\ FITTING} = 110 + 250 =$ 350 Ft

Absolute Consulting Engineers
Total Design and R&D Engineers
(949) 852-8700
Absoluteco.Com

REVISIONS

SHEET NUMBER
JOB NAME:
RE:
DATE

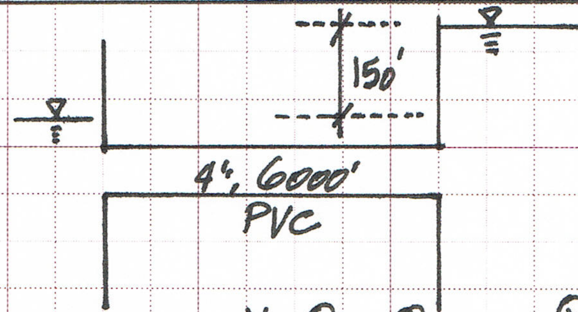
DETAILS — ENGINEERING & CONSULTING

IF A 4" PVC PIPE 6000 Ft LONG IS TO TRANSFER H_2O @ 68°F BETWEEN 2 RESEVOIRS WITH 150 Ft SURFACE ELEVATION DIFFERENCE.

FIND FLOW RATE Q?

$$\frac{V_1^2}{2g} + Z_1 + \frac{P_1}{\gamma_1} \pm W = \frac{V_2^2}{2g} + Z_2 + \frac{P_2}{\gamma} + h_f$$

$$V_1 \,\&\, V_2 = \phi \; ; \; \frac{P_1}{\gamma_1} = \frac{P_2}{\gamma_2} \Rightarrow Z_1 = Z_2 + h_f$$



$$150 = h_f$$

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

$$= f \frac{6000}{4/12} \frac{V^2}{2(32.2)}$$

$$= f \frac{6000}{0.333} \frac{1}{64.4} \frac{Q^2}{0.0873}$$

$$V = \frac{Q}{A} = \frac{Q}{\frac{\pi}{4}(4/12)^2} = \frac{Q}{0.0873 \text{ ft}^2}$$

$$Re = \frac{VD}{\nu} = \frac{Q}{A}\frac{D}{\nu} = \frac{Q}{0.0873}\frac{0.333}{1.217\times10^{-5}} = 3.14\times10^5 Q$$

(1) $Re = 3.14\times10^5 Q$

(2) $fQ^2 = 0.00409$

Q	Re	f	fQ		
0.50	1.57×10^5	0.0165	0.004125	≠	0.00409
0.49	1.5386×10^5	0.0165	0.00396	≠	0.00409
0.496	1.557×10^5	0.0165	0.00406	≈	0.00409

∴ $Q = 0.496 \text{ Ft}^3/\text{sec}$

Absolute Consulting Engineers
Total Design and R&D Engineers
(949) 852-8700
Absoluteco.Com

REVISIONS

SHEET NUMBER
JOB NAME:
RE:
DATE

ENGINEERING & CONSULTING

DETAILS

(a) FIND EGL & HGL FROM RESERVOIR TO "A"

$$Z_R - Z_A = \frac{V^2}{2g} + \frac{P}{\gamma} + Z_A + K\frac{V^2}{2g}$$

$$60 = \frac{V^2}{2g} + \frac{P}{\gamma} + Z_A + 0.5\frac{V^2}{2g}$$

$$\frac{V^2}{2g} = 1.66$$

$$\frac{P}{\gamma} + Z_A = 60 - \frac{V^2}{2g} - 0.5\frac{V^2}{2g} = 60 + \frac{V^2}{2g}(-1.5)$$

HGL $\frac{P}{\gamma} + Z_A = 57.51$ Ft ; $\frac{V^2}{2g} + \frac{P}{\gamma} + Z_A = 59.17$ Ft EGL

(b) POINT B TO RESERVOIR

$$60 = \frac{V^2}{2g} + \frac{P}{\gamma} + Z_B + 0.5\frac{V^2}{2g} + 0.02\frac{80'}{6/12'}\frac{V^2}{2g}$$

HGL $\frac{P}{\gamma} + Z_B = 60 - \left(1.5 + 0.02\left(\frac{80}{0.5}\right)\right)1.66 = 52.19$

EGL $\frac{V^2}{2g} + \frac{P}{\gamma} + Z_B = 52.19 + 1.66 = 53.85$

(C) TO POINT D

$$60 = \frac{V^2}{2g} + \frac{P}{\gamma} + Z_D + (10 + 0.5)\frac{V^2}{2g} + 0.02\frac{200}{0.5}\frac{V^2}{2g}$$

HGL $\frac{P}{\gamma} + Z_D = 60 - (10.5 + 9)\frac{V^2}{2g} = 27.6$ Ft

EGL $\frac{V^2}{2g} + \frac{P}{\gamma} + Z_D = 27.6 + 1.66 = 29.26$ Ft

(d) TO POINT "C"

HGL $\frac{P}{\gamma} + Z_C = 35.59$ Ft

EGL $\frac{P}{\gamma} + Z_C + \frac{V^2}{2g} = 37.25$ Ft

(e) AT POINT E THE HGL IS AT FREE WATER SURFACE

$$\frac{P}{\gamma} + Z_E = \phi$$

EGL $\frac{P}{\gamma} + Z_E + \frac{V_E^2}{2g} = \phi + 16(1.66) = 26.6$ Ft

Absolute Consulting Engineers
Total Design and R&D Engineers
(949) 852-8700
Absoluteco.Com

REVISIONS

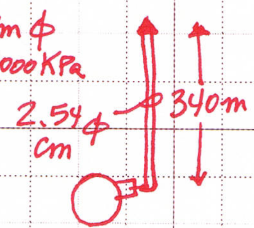
SHEET NUMBER 1/
JOB NAME: HYDRAULICS
RE:
DATE 3/30/05

DETAILS

ENGINEERING & CONSULTING

WATER IS PUMPED THROUGH a PIPE 340 m ABOVE. PUMP & TANK ARE AT SAME LEVEL. PUMP IS PUMPED THROUGH 2.54 cm AND IT DISCHARGES TO a 0.5cm ϕ NOZZLE @ 7000 KPa. FLOW IS @ 0.002 m³/s. WHAT IS APPROXIMATE PRESSURE AT DISCHARGE SIDE OF THE PUMP?

$Q = 0.002 \frac{m^3}{s}$



$$\frac{P_1}{\gamma} + Z_1 + \frac{V_1^2}{2g} = \frac{P_2}{\gamma} + Z_2 + \frac{V_2^2}{2g}$$

(? , 0 , 7000 , 340 ; $\gamma \approx 1000\ Kg/m^3$; $V_1 = \left(\frac{Q_1}{A_1}\right)^2$, $V_2 = \left(\frac{Q_2}{A_2}\right)^2$)

$$P_1 + \left(\frac{Q_1}{A_1}\right)^2 \frac{\gamma}{2g} = P_2 + Z_2\gamma + \left(\frac{Q_2}{A_2}\right)^2 \frac{\gamma}{2g}$$

$$P_1 = P_2 + Z_2\gamma + \left[\left(\frac{Q_2}{A_2}\right)^2 - \left(\frac{Q_1}{A_1}\right)^2\right]\frac{\gamma}{2g} = 7000\,KPa + \frac{340m \; 998.3\frac{Kg}{m^3} \; 9.81\frac{m}{s}}{\frac{Kg.m}{s^2.N}\left(10^3 N/m^2 KPa\right)}$$

$$\frac{\gamma}{2g} = \frac{\rho}{2}$$

$$+ \frac{998.3}{2}\frac{Kg}{m^3}\left[\frac{(0.002)^2}{(A_2)^2} - \frac{(0.002)^2}{(A_1)^2}\right]$$

$A_2 = 2.0\times10^{-5}$, $A_1 = 5.1\times10^{-4}$

$= 15310\ KPa$

$$A_2 = \frac{\pi D_2^2}{4} = \frac{\pi}{4}\left(0.5cm\left(\frac{1m}{100cm}\right)\right)^2 = 2.0\times10^{-5}\,m^2$$

$$A_1 = \frac{\pi D_1^2}{4} = \frac{\pi}{4}\left(2.54\left(\frac{1m}{100cm}\right)\right)^2 = 5.1\times10^{-4}\,m^2$$

UNITS: $$\frac{Q^2\rho}{2A^2} = \frac{(m^3/s)^2(998.3\ Kg/m^3)}{\frac{Kg.m}{s^2.N}\left(10^3 \frac{N}{m^2.KPa}\right)2(m^2)^2} = KPa$$

$$Z\rho g = (m)(998.3\,Kg/m^3)\,9.81\,m/s^2 \Big/ \left[\left(\frac{Kg.m}{s^2.N}\right)\left(10^3 \frac{N}{m^2.KPa}\right)\right]$$

$= KPa$

Absolute Consulting Engineers
Total Design and R&D Engineers
(949) 852-8700
Absoluteco.Com

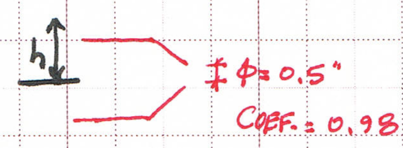
REVISIONS

SHEET NUMBER 1
JOB NAME: HYDRAULICS
RE:
DATE 3/30/05

DETAILS — ENGINEERING & CONSULTING

PRESSURE IS MAINTAINED @ 100 Psig IN A FIRE HOSE WITH NOZZLE DIAMETER OF 0.5 in. NOZZLE COEFFICIENT IS 0.98, & WATER TEMPRATURE IS 70°F. WHAT IS FLOW RATE AT NOZZEL ~~OUTLET~~?

HEAD EQUIV. TO "100Psig"



$$h = \frac{P g_c}{\rho g} = \frac{\left(100 \frac{lb}{in^2}\right)\left(32.2 \frac{Ft \cdot lbm}{lb_f \cdot s^2}\right)\left(144\ in^2/Ft^2\right)}{32.2\ Ft/s^2 \quad 62.3\ lbm/ft^3}$$

$$= 100Psi\ \frac{32.2(144)}{32.2(62.3)} = 100\left(\frac{144}{62.3}\right) = 231\ Ft$$

TORRICELLI EQN: $V = C_v\sqrt{2gh} = 0.98\left[2\left(32.2\frac{Ft}{s^2}\right)231\ Ft\right]^{1/2} = 120\ Ft/s$

$$Q = VA = (120\ Ft/s)\left(\frac{\pi}{4}\left(\frac{0.5}{12}\right)^2\right) = (120\ Ft/s)(0.0014\ Ft^2) * \frac{1\ gal}{0.134\ Ft^3}\left(60\frac{s}{min}\right)$$

$= 75$ GPM

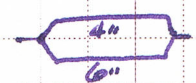
Absolute Consulting Engineers
Total Design and R&D Engineers
(949) 852-8700
Absoluteco.Com

REVISIONS

SHEET NUMBER 1
JOB NAME: HYDRAULICS
RE:
DATE 3/30/05

DETAILS — ENGINEERING & CONSULTING

EXISTING 6" STEEL WATER PIPE CANNOT MEET 2.4 FT³/S SOURCE. A 4" PIPE IS PARALLELED. BOTH PIPES ARE 1400 FT LONG. WHAT IS THE FLOW RATE IN 4" PIPE?



- $h_{f6} = \frac{f_6 L_6 V_6^2}{2 D_6 g} = \frac{f_4 L_4 V_4^2}{2 D_4 g} = h_{f4}$ (with $L_6 = 1400$, $L_4 = 1400$; $2\,\frac{6"}{12"}\,g$; $2\,\frac{4"}{12}\,g$)

  $f_6 V_6^2 / D_6 = f_4 V_4^2 / D_4$

  $\frac{f_6}{6} V_6^2 = \frac{f_4}{4} V_4^2$

$h_{f6"} = h_{f4"}$

$A_4 = \frac{\pi 4^2}{4} \frac{1}{144} = 0.087\ ft^2$

$A_6 = \frac{\pi 6^2}{4} \frac{1}{144} = 0.196\ ft^2$

$\epsilon = 0.0002\ ft$

$\epsilon/D = \epsilon/D_{4"} = \frac{0.0002}{6/12}$ OR $4/12$

- $Q = A_6 V_6 + V_4 A_4 = 2.4\ \frac{ft^3}{s} = 0.196(V_6) + (0.087) V_4$

  $2.4 = 0.196 V_6 + 0.087 V_4$

- ASSUME $Re = 5\times10^5$ → $0.0002\left(\frac{12}{4}\right) = 0.0006$; $0.0002\left(\frac{12}{6}\right) = 0.0004$; $\nu|_{60°F} = 1.217\times10^{-5}\ ft^2/s$

  FIND/ESTIMATE $f_4 = 0.0185$; $f_6 = 0.017$ ⇒ $\frac{0.0185}{6} V_6^2 = \frac{0.017}{4} V_4^2$

  FIND $V_4 = 7.0\ ft/s$; $V_6 = 9.1\ ft/s$ → $Re_4 = 1.9\times10^5$; $Re_6 = 3.7\times10^5$

- $f = 0.25 / \left[\log\left(\frac{\epsilon/D}{3.7} + \frac{5.74}{Re^{0.9}}\right)\right]^2$ Plug in New ϵ/D; Re

  $f_6 = 0.0174$ close enough 0.017

  $f_4 = 0.0195$ ≈ 0.0185

- $Q = AV = 0.087\ (7.0\ ft/s) =$

  $= 0.609\ ft^3/s$

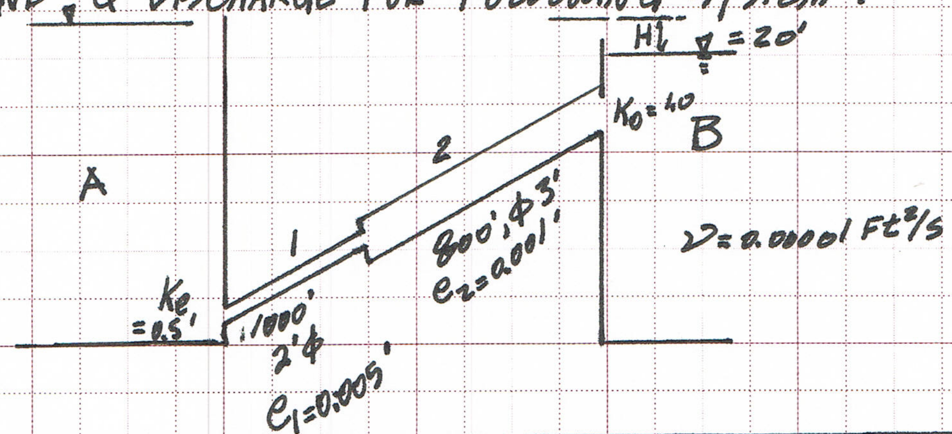
Absolute Consulting Engineers
Total Design and R&D Engineers
(949) 852-8700
Absoluteco.Com

REVISIONS

SHEET NUMBER
JOB NAME:
RE:
DATE

DETAILS | ENGINEERING & CONSULTING

FIND Q DISCHARGE FOR FOLLOWING SYSTEM?



- TOTAL ENERGY A → B

$$Z_A - Z_B + \phi + \phi = Ke_1 \frac{V_1^2}{2g} + f_1 \frac{L_1}{D_1}\frac{V_1^2}{2g} + K_{EXPANS.}\frac{V_1^2}{2g} + f_2 \frac{L_2}{D_2}\frac{V_2^2}{2g} + K_o \frac{V_2^2}{2g}$$

$$H = \left(Ke_1 + f_1 \frac{L_1}{D_1}\right)\frac{V_1^2}{2g} + K_{EXP.}\frac{V^2}{2g} + \left(f_2 \frac{L_2}{D_2} + K_o\right)\left(\frac{V_2^2}{2g}\right)$$

$$K_{EXP.} = \frac{(V_1 - V_2)^2}{2g}$$

$$20 = H = \left(0.5 + f_1\, 500\right)\frac{V_1^2}{2g} + \frac{(V_1 - V_2)^2}{2g} + \left(1.0 + f_2 \frac{800}{3}\right)\frac{V_2^2}{2g}$$

NOTE: $V_1 A_1 = V_2 A_2 = V_1 \pi \frac{2^2}{4} = V_2 \frac{3^2 \pi}{4}$

$V_1 = \frac{9}{4} V_2$ $\quad \frac{V_2}{V_1} = 4/9$

- $$20 = \frac{V_1^2}{2g}\left[\left(0.5 + f_1\, 500\right) + \frac{(V_1 - V_2)^2}{V_1^2} + \left(1.0 + f_2 \frac{800}{3}\right)\left(\frac{V_2}{V_1}\right)^2\right]$$

- FIND f_1 & f_2 → $\frac{e_1}{D_1} = 0.0025$ $\quad \frac{e_2}{D_2} = 0.00033$

MOODY DIAGRAM $f_1 = 0.025$ $\quad f_2 = 0.015$

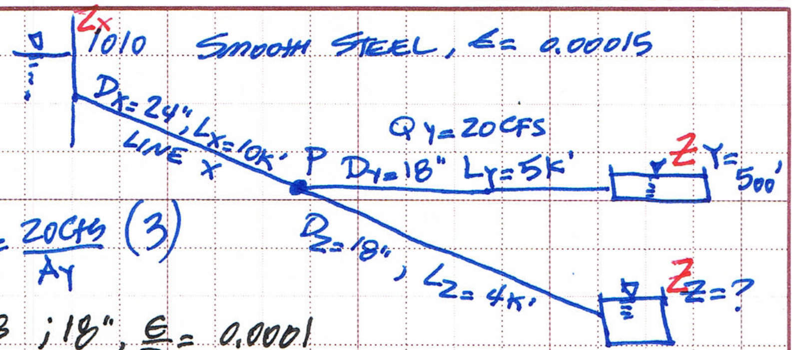
SIMPLIFY:

- $20 = \frac{V_1^2}{2g}\left(1.01 + 500 f_1 + 52.6 f_2\right)$ (?) SUBSTITUTE f_1 & f_2

$V_1 = 9.49$ & $V_2 = 4.21$

- FIND Re's $Re_1 = 1{,}898{,}000$; $Re_2 = 1{,}263{,}000$ → $f_1 = 0.025$; $f_2 = 0.016$
- SOLVE for V_1 again → $V_1 = 9.46$ ft/sec OK.

$$\therefore Q = V_1 A_1 = 9.46\, \pi \left(\frac{4}{4}\right) = 29.8 \text{ cfs}$$



GIVEN FOLLOWING FIND ELEVATION "Z"?

$$Q_X = Q_Y + Q_Z$$

$$A_X V_X = A_Y V_Y + A_Z V_Z$$

$$20 CFS = A_Y V_Y \qquad V_Y = \frac{20 CFS}{A_Y} \quad (3)$$

24" PIPE, $\frac{\epsilon}{D} = 0.000\,08$; 18", $\frac{\epsilon}{D} = 0.0001$

$f_x = 0.0115$ $\quad f_Y = 0.012$ $\quad f_Z = 0.012$ ASSUME Re is V. HIGH

BERNOULI → Y ⇒ $Z_{X_1} - f_X\left(\frac{L}{D}\right)_X \frac{V_X^2}{2g} - f_Y\left(\frac{L}{D}\right)_Y \frac{V_Y^2}{2g} = Z_Y + \frac{V_Y^2}{2g}$ (1)

VELOCITY HEAD ONLY EFFECT 2-3% IN SOLUTION

$$Z_{X_1} - f_X\left(\frac{L}{D}\right)_X \frac{V_X^2}{2g} - f_Z\left(\frac{L}{D}\right)_Z \frac{V_Z^2}{2g} = Z_Z + \frac{V_Z^2}{2g} \quad (2)$$

SOLVE FOR EQUATION (1):

$$1010 - 0.0015\left(\frac{10{,}000}{2}\right)\frac{V_X^2}{2(32.2)} - 0.012\left(\frac{5000}{1.5}\right)\frac{\left(20/\frac{\pi}{4}(1.5)^2\right)^2}{2(32.2)} = 500 + \frac{\left[20/\left(\pi/4\,(1.5)^2\right)\right]^2}{2(32.2)}$$

$A_X = \frac{\pi}{4}(2)^2 = \pi\ Ft^2$; $A_Z = A_Y = \frac{\pi}{4}(1.5)^2 = 1.77\ Ft^2$ $\qquad V_X = 22.0$ FPS

(3) $V_Z = (1/A_Z)(A_X V_X - A_Y V_Y) = 1/A_Z\,(A_X V_X - 20) = \frac{1}{1.77}(22\pi - 20) = V_Z = 27.8$ FPS

SUBSTITUTE IN (2) FOR (Z_Z)

$$1010 + -0.019\left(\frac{10000}{2}\right)\frac{(22)^2}{64.4} - 0.012\left(\frac{4000}{1.5}\right)\frac{(27.8)^2}{64.4} = \frac{(27.8)^2}{64.4} + Z_Z$$

$Z_Z = 186$ Ft

GIVEN $V_Z = 27.8$; $V_X = 22$ Ft/s ; $V_Y = 20/1.77 =$ Ft/s & PIPE DIAMETERS FIND Re FOR EACH

$Re = \frac{VD}{\nu}$ USE MOODY DIAGRAM TO FIND

$f_X = 0.0125$ $\qquad f_Y = 0.013$ $\qquad f_Z = 0.0125$

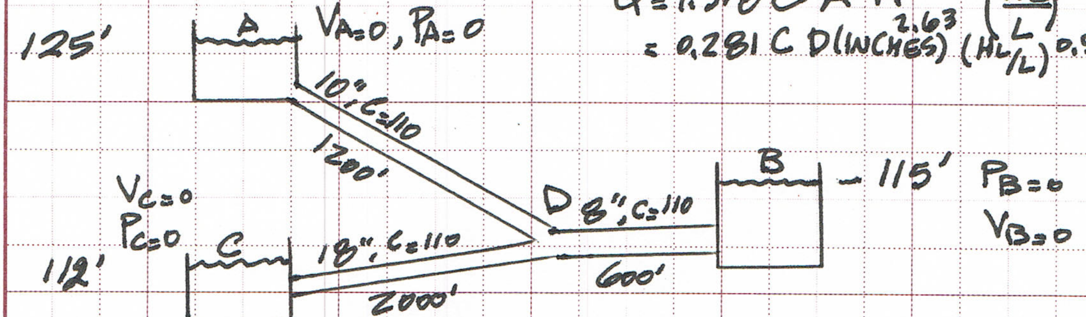
REPEAT & REDO PROBLEM $f_X\left(\frac{L}{D}\right)_X \frac{V_X^2}{2g} = 422$ THEN

$V_X = 21.8$, $V_Z = 27.4$ FPS

& $Z_Z = 188'$ FINAL ANSWERE

DETERMINE GPM, FRICTION LOSS, DIRECTION IN EACH PIPE.

$$Q = 1.318\,C\,A\,R^{0.63}\left(\frac{h_L}{L}\right)^{0.54} = 0.281\,C\,D(\text{INCHES})^{2.63}\left(\frac{H_L}{L}\right)^{0.54} = GPM$$



(1) $\frac{P_A}{\gamma} + Z_A + \frac{V_A^2}{2g} = \frac{P_D}{\gamma} + Z_D + \frac{V_D^2}{2g} + H_{L\,AD}$ • VELOCITY HEAD @ D IS IGNORED

(2) $\frac{P_B}{\gamma} + Z_B + \frac{V_B^2}{2g} = \frac{P_D}{\gamma} + Z_D + \frac{V_D^2}{2g} + H_{LBD}$ • MINOR LOSSES IGNORED

(3) $\frac{P_C}{\gamma} + Z_C + \frac{V_B^2}{2g} = \frac{P_D}{\gamma} + Z_D + \frac{V_D^2}{2g} + H_{LCD}$ • Σ ALGBRAIC $Q|_D = \phi$

(1) $Z_A = \frac{P_D}{\gamma} + Z_D + H_{LAD} = 25 = P_D/\gamma + Z_D + H_{LAD} \Rightarrow H_{LAD} = 25 - Y_D$

(2) $Z_B = P_D/\gamma + Z_D + H_{LBD} = 15 = \downarrow + H_{LBD} \Rightarrow H_{LBD} = 15 - Y_D$

(3) $Z_C = P_D/\gamma + Z_D + H_{LCD} = 12 = + H_{LCD} \Rightarrow H_{LCD} = 12 - Y_D$

TRIAL	Y_D	H_{LAD}	H_{LBD}	H_{LCD}	Q_{AD}	Q_{BD}	Q_{CD}	Q_{TOTAL}
1	13	12	2.0	-1.0	1097	337	-1021	413
2	14.	11	1.0	-2.0	1046	232	-1484	-209
3	13.8	11.2	1.2	-1.8	1056	256	-1402	-90
4	13.6	11.4	1.4	-1.6	1067	278	-1316	29
5	13.63	11.37	1.37	-1.63	1065	275	-1329	11
6	13.65	11.35	1.35	-1.65	1064	273	-1338	-1
7	13.648	11.352	1.352	-1.652	1064	273	-1337	0

$Q_{AD} = 0.281(110)\,10^{2.63}\left(\frac{H_L}{1200}\right)^{0.54}$

$Q_{BD} = 0.281(110)\,8^{2.63}\left(\frac{H_L}{600}\right)^{0.54}$

$Q_{CD} = 0.281(110)(18)^{2.63}\left(\frac{H_L}{2000}\right)^{0.54}$

PIPE	Q(GPM)	FRICTION LOSS	FLOW DIRECTION
AD	1064	11.352	A TO D
BD	273	1.352	B TO D
CD	-1337	-(1.652)	D TO C

$$Q_{TOTAL} = Q_{AD} + Q_{BD} + Q_{CD} = 286\,(H_{LAD})^{0.54} + 232\,(H_{LBD})^{0.54} + 1021\,(H_{LCD})^{0.54}$$

WATER FLOWS @ V=4.2 Ft/s in a 2"ϕ CONNECTED TO A REDUCER 1.5"ϕ. WHAT IS THE FINAL VELOCITY?

$$Q_1 = V_1 A_1 = Q_2 = V_2 A_2 = \left(4.2\ Ft/s\right)\frac{1}{144}\left(\frac{\pi D_1^2}{4}\right) = V_2 \frac{1}{144}\left(\frac{\pi D_2^2}{4}\right)$$

$$\frac{4.2}{144}\ \frac{Ft}{s}\left(\frac{Ft^2}{in^2}\right)\pi\frac{2^2}{4} = V_2 \frac{1}{144}\left(\pi\ \frac{(1.5)^2}{4}\right) \Rightarrow$$

$$V_1 D_1^2 = V_2 D_2^2$$

$$(4.2)\ 2^2 = V_2\ (1.5)^2$$

$$V_2 = \frac{4.2(4)}{2.25} = 7.5\ \frac{Ft}{s}$$

٣

Absolute Consulting Engineers
Total Design and R&D Engineers
(949) 852-8700
Absoluteco.Com

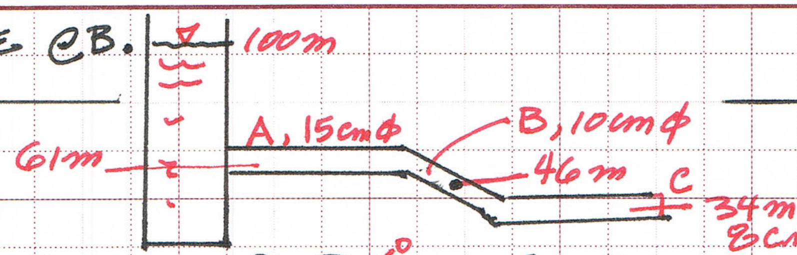
REVISIONS

SHEET NUMBER 1
JOB NAME: HYDRAULICS
RE: BERNOULI
DATE 3/30/05

DETAILS

ENGINEERING & CONSULTING

FIND PRESSURE @B.



APPLY BERNOULLI EQUATION

$P_C = \phi$ FREE JET

$V_A = \phi$ RESERVOIR

$P_A = \phi$

$$\frac{P_A}{\rho g} + Z_A + \frac{V_A^2}{2g} = \frac{P_B}{\rho g} + Z_B + \frac{V_B^2}{2g} = \frac{P_C}{\rho g} + Z_C + \frac{V_C^2}{2g} = Z_A = 100$$

(with $\frac{P_A}{\rho g} = 0$, $\frac{V_A^2}{2g} = 0$, $\frac{P_C}{\rho g} = 0$)

$$Z_A = 100 = \frac{P_B}{\rho g} + 46m + \frac{V_B^2}{2g} = 34 + \frac{V_C^2}{2g} \Rightarrow V_C = 36 m/s$$

$$V_C A_C = V_B A_B$$ CONTINUITY OF MASS

$$(36 m/s)\left(\frac{\pi D_C^2}{4}\right) = V_B\left(\frac{\pi D_B^2}{4}\right)$$

$$36 D_C^2 = V_B D_B^2 \rightarrow V_B = 36\frac{D_C^2}{D_B^2} = 36\left(\frac{8}{10}\right)^2 = 23 m/s$$

$$\frac{P_B}{\rho g} + 46m + \frac{(23)^2}{2g} = 34 + \frac{(36)^2}{2g} = 100$$

$$\frac{P_B}{(998.23\frac{kg}{m^3})(9.8 m/s^2)\frac{N s^2}{kg \cdot m}\left(\frac{1 KN}{1000 N}\right)} + 46^m + \frac{(23)^2 m^2/s^2}{(2)9.81\frac{m}{s^2}} = 34m + \frac{36^2 m^2/s^2}{2(9.81 m/s^2)} = 100m$$

$$P_B = 265 KN/m^2$$

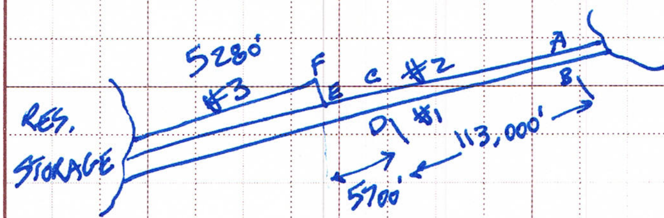
Absolute Consulting Engineers
Total Design and R&D Engineers
(949) 852-8700
Absoluteco.Com

REVISIONS

SHEET NUMBER
JOB NAME: HYDRAULICS
RE:
DATE 9/15/05

DETAILS — ENGINEERING & CONSULTING

2 PIPES FEED STORAGE RESERVOIR. PIPE #2 IS EXTENDED & BYPASS THIRD PIPE 52,800 Ft. $Q_1 = 74$ mgd, $Q_3 = 61$ mgd



PRESSURE GAGE

POINT	ELEV. GAGE, Ft	GAGE READING Psi
A	192	207
B	26	179
C	23	170
D	397	3
E	192	215
F	26	198

HAZEN WILLIAMS $V = 1.318\,C\,R^{0.63}\,S^{0.54}$ $S = \frac{h_L}{L}$

HYDRAULIC GRADE LINE $= Z + Psi \frac{\#}{in^2} \frac{144\ in^2/ft^2}{62.4\ lb/ft^3}$ $R = d/4$

$@B \Rightarrow 192 + 215(144/62.4) = 688'$

$@D \Rightarrow 26 + 198(144/62.4) = \underline{483'}$

$205'$ $\ell = 113,000$

$S^{0.54} = \left(205/113,000\right)^{0.54} = 0.0331$

$V_1 = \frac{Q_1}{A_1} = \frac{74(10^6)/24(3600)(7.48)}{(58/12)^2\,\pi/4} = \frac{114.5\ CFS}{A_1} = 6.23\ FPS$

$R_1^{0.63} = \left(\frac{58}{12(4)}\right)^{0.63} = 1.127$ $V = 6.23 = 1.318\,C(1.127)\,0.0331 \Rightarrow \underline{\underline{C_1 = 127}}$

$@F \Rightarrow 23 + 170(144/62.4) = 416'$

$@G \Rightarrow 397 + 3(144/62.4) = \underline{404'}$

$h_L = 12'$

$\ell = 52,800'$; $S_3^{0.54} = \left(\frac{12}{52,800}\right)^{0.54} = 0.0108$

$Q_3 = 61\ mgd = 94.4\ cfs$; $R_3^{0.63} = \left(\frac{78}{4(12)}\right)^{0.63} = 1.358$

$V_3 = \frac{Q_3}{A_3} = \frac{94.4}{\pi/4\,(78/12)^2} = 2.84 = 1.318(1.358)(C)\,0.0108$ $\underline{\underline{C_3 = 147}}$ ←

$@A \rightarrow 192 + 207(144/62.4) = 670'$

$@C \rightarrow 26 + 179(144/62.4) = \underline{439'}$

$\Delta h_L = 231'$

$@E \rightarrow 439\big|_{@C} - \left(\frac{5700}{113000}\right)(670 - 439)\big|_{C\ to\ E} = 427.3'$

$@F \rightarrow 23 + 170(144/62.4) = 416'$ $= \underline{416}$

$11.3'$

} 36" ϕ CROSS CONNECTION

$V_x = V_3\left(\frac{d_3}{d_x}\right)^2 = 2.84\left(\frac{78}{36}\right)^2 = 13.3\ F/S$

$\frac{V_x^2}{2g} = 2.75$; $h_L = 11.3 \Rightarrow \frac{h_L}{V^2/2g} = 11.3/2.75 \Rightarrow h_L = 4.11\ V_x^2/2g$

MAJORITY OF LOSSES ARE ENTRANCE & EXITS

Absolute Consulting Engineers
Total Design and R&D Engineers
(949) 852-8700
Absoluteco.Com

REVISIONS

SHEET NUMBER
JOB NAME: HYDRAULICS
RE:
DATE 9/15/05

DETAILS | ENGINEERING & CONSULTING

EXISTING RESERVOIR IS FED FROM 825' ELEVATION WITH (2) PIPES (47 mi)
A THIRD PIPE INTERCEPTS PIPE #2 WITH 36"Φ FOR 20' & THEN PARALLEL TO PIPE #2

NEGLECT MINOR LOSSES

	#1	#2	#3	CONNECTION
MILE	47	47	10 (MILES)	20' Ft
Φ, "	58"	60"	78"	36"
f	0.013	0.012	0.012	0.012
LINING	MORTAR	ENAMEL	ENAMEL	ENAMEL

EXISTING $\Delta H = f\frac{\ell}{d}\frac{V^2}{2g} = 825 - 427 = 398'$

$$V = \left(\frac{\Delta H\, 2g\, d}{\ell f}\right)^{1/2}$$

$$Q = AV = A\left(\Delta H 2gd/\ell f\right)^{1/2}$$

$$Q_1^2 = \left(\pi\frac{d_1^2}{4}\right)^2\left(\Delta H\ 2g\ d_1/\ell_1 f_1\right) \Rightarrow \Delta H = \frac{Q_1^2}{(\frac{\pi}{4}(d_1^2))^2}\frac{f_1\ell_1}{d_1 2g}$$

$$Q_1 = \frac{\pi}{4}\left(\frac{58}{12}\right)^2\left(\frac{398(58/12)64.4}{47(5280)(0.013)}\right)^{1/2} = 114\ cfs = 73.7\ mgd$$

$$\Delta H = \frac{Q_2^2}{(\frac{\pi}{4}d_2^2)^2}\frac{f_2\ell_2}{d_2 2g}$$

$$1 = \frac{Q_1^2}{Q_2^2}\frac{f_1\ell_1}{f_2\ell_2}\frac{d_2^5}{(d_1)^5}$$

$$1 = \frac{Q_1}{Q_2}\left(\frac{d_2}{d_1}\right)^2\sqrt{\frac{f_1}{f_2}\frac{d_2}{d_1}}$$

$$Q_2 = Q_1 \frac{d_2^2}{d_1^2}\sqrt{\frac{f_1}{f_2}\frac{d_2}{d_1}} = 73.7\left(\frac{60}{58}\right)^{5/2}\left(\frac{0.013}{0.012}\right)^{1/2} = 83.3\ mgd$$

NEW FOR 10 MILES (a) $Q_2 = Q_{2a} + Q_{2b}$; $h_a = h_b$

$$\frac{\pi d_2}{4}V_2 = \frac{\pi d_a^2}{4}V_a + \frac{\pi d_b}{4}V_b \qquad d_b = d_2;$$

$$V_2 d_2^2 = V_a d_a^2 + V_b d_b^2$$

(1) $V_2 = V_a\left(\frac{d_a}{d_b}\right)^2 + V_b$

(b) $h_a = h_b = f_a\frac{\ell_a}{d_a}\frac{V_a^2}{2g} = f_b\frac{\ell_b}{d_b}\frac{V_b^2}{2g} =$

(2) IF $f_a \doteq f_b \Rightarrow V_a^2 = \frac{d_a}{d_b}V_b^2$

USE (b) FOR ORIGINAL RUN

$$f_2\frac{\ell_2}{d_2}\frac{V_2^2}{2g} + f_b\frac{\ell_b}{d_b}\frac{V_b^2}{2g} = 398'$$

(3) $\frac{\ell_2}{\ell_b}V_2^2 + V_b^2 = \frac{2g\,d_b}{f\ell_b}398$

SOLVING (1), (2), & (3)

$V_2 = 2.92V_b$; $V_a = 2.84\ FPS$

$$Q_b = \frac{\pi}{4}\left(\frac{60}{12}\right)^2 2.49 = 48.9\ cfs = 31.6\ mgd$$

$$Q_a = \frac{\pi}{4}(78/12)^2(2.84) = 94.3\ cfs = 61.0\ mgd$$

$$Q_2 = Q_a + Q_b = 92.6\ mgd$$

VELOCITY IN 36" PIPE (20' ONLY)

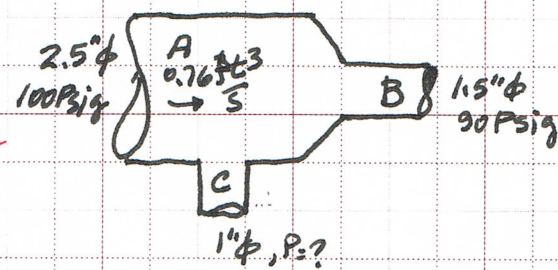
$$V_x = \left(\frac{d_a}{d_x}\right)^2 V_a = \left(\frac{78}{36}\right)^2 2.84 = 13.3\ Ft/s$$

HEAD LOSS THROUGH 36" PIPE, 20 Ft

$$h_L = f\frac{\ell}{d}\frac{V^2}{2g} = 0.012\left(\frac{20}{3}\right)\left(\frac{13.3^2}{64.4}\right) = 0.22'$$

398' >> 0.22 ∴ NEGLIGIBLE.

WATER FLOWING IN A SCHEDULE 40 STEEL PIPE AS SHOWN.
WHAT IS FLOW RATE @ C?



2.469"ϕ
0.0332 ft²

1.610"ϕ
0.0141 ft²

INSIDE DIAMETER
= 1.049"
= 0.006 Ft²

$$E_A = E_B$$

$$\frac{P_A}{\gamma} + Z_A + \frac{V_A^2}{2g} = \frac{P_B}{\gamma} + Z_B + \frac{V_B^2}{2g} \qquad (Z_A = 0,\ Z_B = 0)$$

$$\frac{100\ \text{Psi}\ 144\ \text{in}^2/\text{Ft}^2}{62.4\ \text{lbf}/\text{ft}^3} + \frac{V_A^2}{2g} = \frac{90\ \text{Psi}\ 144}{62.4} + \frac{V_B^2}{2g}$$

$$(100-90)\frac{144}{62.4} = (V_B^2 - V_A^2)/2g =$$

$$\frac{1440}{62.4}(2)(32.2) = V_B^2 - 23^2 \Rightarrow V_B = 45\ \text{Ft/s}$$

$$Q_A = V_A A$$
$$0.76\ \frac{\text{Ft}^3}{\text{s}} = V_A\ 0.0332$$
$$V_A = 23\ \text{Ft/s}$$

$$\dot{m}_A = \dot{m}_B + \dot{m}_c = \rho_A V_A A_A = \rho_B V_B A_B + \rho_c V_c A_c$$

$$V_A A_A = V_B A_B + V_c A_c$$

$$(0.0332)23 = (0.0141)(45) + (0.006)V_c$$

$$V_c = 22\ \text{Ft/s}$$

$$Q = V_c A_c = (22)(0.006) = 0.13\ \text{Ft}^3/\text{s}$$

Absolute Consulting Engineers
Total Design and R&D Engineers
(949) 852-8700
Absoluteco.Com

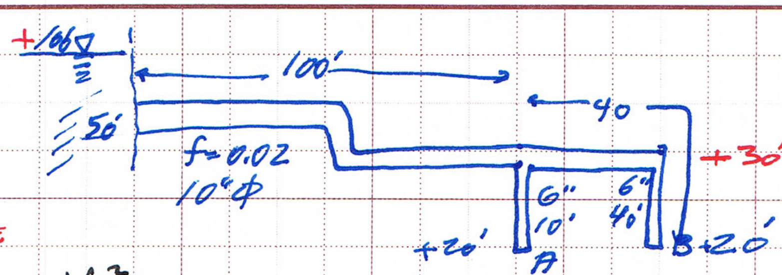
REVISIONS

SHEET NUMBER
JOB NAME: HYDRAULICS
RE: PIPING
DATE 9/19/05

DETAILS — ENGINEERING & CONSULTING

INSTALLATION SHOWN

WHAT IS Q_A OR Q_B ?



PATH 10"φ → 6"A → DISCHARGE

$$-f\frac{L_A}{D_6}\frac{V_{10}^2}{2g} + 80 - f\frac{L_{10}}{D_{10}}\frac{V_{10}^2}{2g} + \phi = \frac{V_A^2}{2g} + 20$$

$$+f\frac{L_B}{D_6}\frac{V_{10}^2}{g} + 80 - f\frac{L_{10}}{D_{10}}\frac{V_{10}^2}{2g} + \phi = \frac{V_B^2}{2g} + 20$$

$$\Big\} \; f\left(\frac{L_A}{D_6}+1\right)V_A^2 = f\left(\frac{L_B}{D_6}\right)+1\,V_B^2$$

$$V_A = \left(\frac{fL_B + D_6}{fL_B + D_6}\right)^{1/2} V_B = 1.365\,V_B$$

$V_A = 1.365\,V_B$

ARE A / MASS

$$(V_{10})\frac{D_{10}^2\pi}{4} = \Sigma\,F_{LOW\,IN} = \Sigma\,F_{OUT} = V_{10}\frac{\pi}{4}D_{10}^2 = V_A\frac{\pi D_6^2}{4} + V_B\frac{\pi D_6^2}{4}$$

$$V_{10} = \left(\frac{6}{10}\right)^2(V_B + 1.36V_B) = 0.853\,V_B$$

$V_{10} = 0.853\,V_B$

$$\left(f\left(\frac{L_A}{D_6}\right)+1\right)V_B^2(1.365)^2 = \left(f\left(\frac{L_B}{D_6}\right)+1\right)V_B^2$$

TO CHECK ?

$$80 - f\frac{L_{10}}{D_{10}}\frac{V_{10}^2\;(0.835\,V_B)^2}{2g} - f\frac{L_B}{D_6}\frac{V_B^2}{2g} = \frac{V_B^2}{2g} + 20 \Rightarrow (60)2g = \left[f\left[\frac{L_{10}}{D_{10}}(0.853)^2 + \frac{L_B}{D_6}\right]+1\right]$$

$$V_B^2 = 60(2)(32.2) \Big/ \left(\left[0.02\left(\frac{100}{10/12}(0.853)^2 + 40/(6/12)\right)\right]+1\right)$$

$$= 890\,(FPS)^2$$

$V_B = 29.8$ FPS

$V_{10} = 0.853\,V_B$

$V_{10} = 26.4$ Ft/S

$$Q = A_{10}V_{10} = \frac{\pi}{4}\left(\frac{10}{12}\right)^2 26.4$$

$Q = 13.85\ Ft^3/S$

WATER PIPE IS 5.1 miles. RESERVOIR ELEVATION IS +480 Ft & TOWN ELEVATION IS 300 Ft. WATER WITHOUT PUMP MUST TRAVEL TO TANKS WITHIN TOWN. PIPE IS CAST IRON WITH DARCY f OF 0.021 WITH Q_{DEMAND} = 1MGD.

a. WHAT IS MINIMUM PIPE?
b. WHAT COMMERCIAL PIPE SIZE?
c. IS f CORRECT VALUE?
d. CALCULATE MANNING "n" & ITS EFFECT.

$Q = 1MGD = 1.55\,CFS$; $f = 0.021$; $H_L = 480 - 300 = 180'$
$L = 5.1 * 5280 = 26,900'$

Darcy Weisbach formula

$$H_L = \frac{fL}{D}\frac{V^2}{2g} = \frac{fL}{D}\cdot\left(\frac{Q}{A}\right)^2\frac{1}{2g}$$

$$D^5 = \left(\frac{16Lf}{H\pi^2}\right)\frac{Q^2}{2g} = \frac{16\,(26900)\,0.021}{180\,\pi^2}\left(\frac{1.55^2}{64.4}\right) = 0.20$$

$\therefore$ $D = 0.73\,Ft = 8.7\,in$ COMMERCIALLY $= 10"$

@ 60°F $\nu = 1\times10^{-5}$; CAST IRON => $\epsilon = 0.00085$

$$\frac{e}{D} = \frac{0.00085}{10/12} = 0.001$$

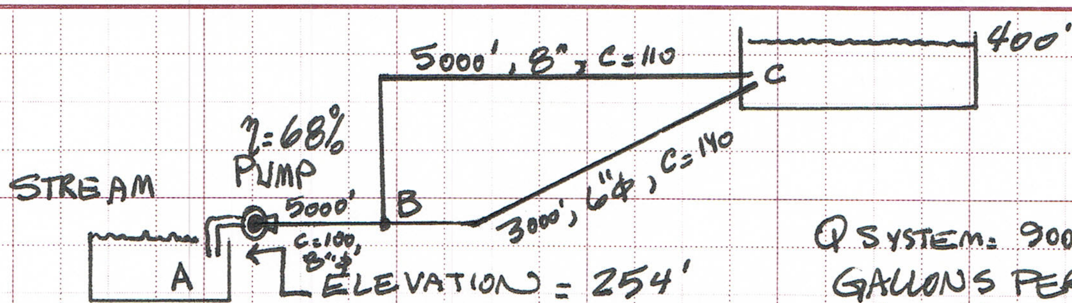
714 501-2204
Rich Smith
Tomis Solar

Absolute Consulting Engineers
Total Design and R&D Engineers
(949) 852-8700
Absoluteco.Com

REVISIONS

SHEET NUMBER
JOB NAME:
RE:
DATE

DETAILS — ENGINEERING & CONSULTING



Q SYSTEM: 900,000 GPD
GALLONS PER DAY
= 625 GPM = 1.39 cfs

a. WHAT IS TOTAL PUMPING HEAD?
b. WHAT HP PUMP IS REQUIRED?
c. IF ELECTRICITY COST IS $15/KW, WHAT IS MONTHLY CHARGE?

- HAZEN WILLIAMS $Q = 1.318\,C A R^{0.63} S^{0.54}$ $\quad S = \frac{h_L}{L}$

FROM A → C: $Q = 1.318\,C A R^{0.63} S^{0.54}$

$$1.39 = 1.318(100)\frac{\pi}{4}\frac{8^2}{12^2}\left(\frac{8}{4(12)}\right)^{0.63}\left(\frac{h_L}{5000}\right)^{0.54} \rightarrow \text{FIND } h_L$$

FROM B → C $h_{L1} = h_{L2} = h_L = 15$ ASSUME

$$Q_1 = 1.318(110)\frac{\pi}{4}\frac{1}{144}(8)^2\left(\frac{8}{4(12)}\right)^{0.63}\left(15/5000\right)^{0.54} \Rightarrow 319\text{ GPM}$$

$$Q_2 = 1.318(140)\frac{\pi}{4}\frac{1}{144}(6)^2\left(\frac{6}{4(12)}\right)^{0.63}\left(15/3000\right)^{0.54} \Rightarrow 251\text{ GPM}$$

570 GPM

570 GPM / 625 GPM = 0.912

$\frac{319}{570} = 0.56 \qquad \frac{251}{570} = 0.44$

∴ NEXT (0.560)(625) = 350 GPM (0.44)625 = 275 GPM

USE THESE Q'S TO GET h_L

$h_{L1} = 17.7\text{ ft} = h_{L2} = h_L$

- TOTAL HEAD: $HP + 254' = 400' + h_{LAB}(62.5) + h_{BC}(17.7)$

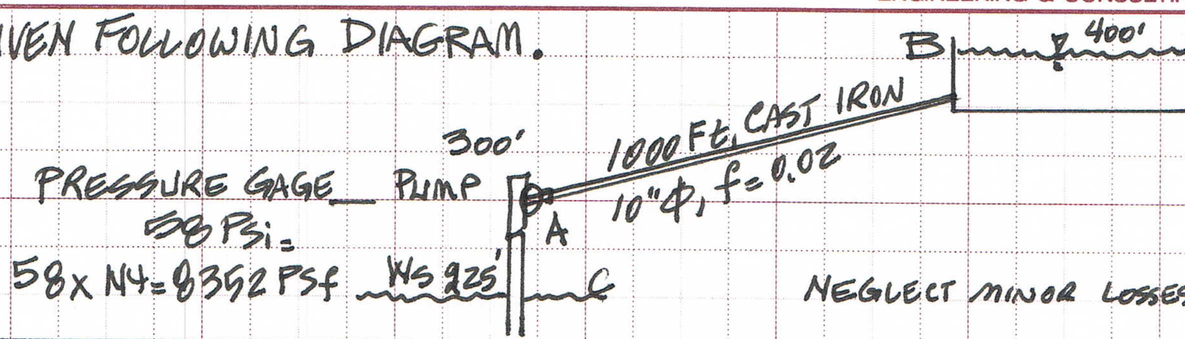
$HP = 400 - ~~HP~~ + 62.5 + 17.7$

$= 226.2\text{ Ft}$

$hp = 62.4(1.39)226.2 / (550)(0.68) = 52.5\text{ HP}$

- COST \$/month = 52.5 (0.746)(30×24)(0.015) = 423.4 \$ ≈ \$424

GIVEN FOLLOWING DIAGRAM.



NEGLECT MINOR LOSSES.

DETERMINE

a. PUMP DISCHARGE AT B GPM
b. η PUMP EFFICIENCY = 0.65, IF 6 HR / DAY OPERATION & 0.03 KWHR WHAT IS MONTHLY COST?

a. $$\frac{P_A}{\gamma} + \frac{V_A^2}{2g} + Z_A = \frac{P_B}{\gamma} + \frac{V_B^2}{2g} + Z_B + h_L$$

$$\frac{8352}{62.4} + \frac{V_A^2}{2g} + 300' = \phi + \phi + 400 + h_L = 400 + \frac{fLV^2}{D\,2g}$$

$$= 400 + \frac{0.02}{10/12}\,1000\,\frac{V_A^2}{2(32.2)} \rightarrow V = 9.75\text{ fps}$$

$$Q = VA = 9.75\,\frac{\pi}{4}\left(\frac{10}{12}\right)^2 = 5.32\text{ cfs} * 7.48 * 60 = 2380\text{ GPM}$$

b. FROM C: TO B:

$$H_P + 225 + \frac{P_C}{\gamma} + \frac{V_C^2}{2g} = 400 + \phi + \phi + h_L$$

(with $\frac{P_C}{\gamma} \to 0$ and $\frac{V_C^2}{2g} \to 0$)

$$H_P = 400 - 225 + \frac{0.02}{10/12}(1000 + 300 - 125)\frac{9.75^2}{(2)32.2}$$

$$= 213.1\text{ Ft}$$

$$hp = \frac{\gamma Q H_P}{550\,\eta} = \frac{(62.4)\,5.32\text{ CFS}\,(213.1)}{(0.65)(550)} = 197.9\text{ hp}$$

$$= 197.9\,(746\text{ W}) = 147\text{ KW}$$

$$\$ = 147\,(30 \times 6)\text{ KWH} * \$0.03/\text{KWH} = \$794.00$$

Absolute Consulting Engineers
Total Design and R&D Engineers
(949) 852-8700
Absoluteco.Com

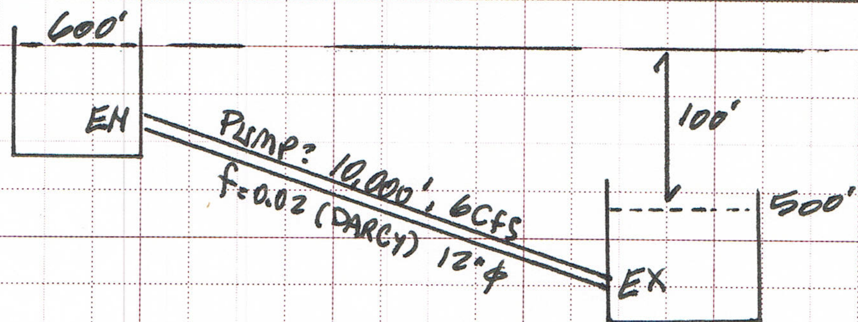
REVISIONS

SHEET NUMBER
JOB NAME:
RE:
DATE

DETAILS

ENGINEERING & CONSULTING

CALCULATE PUMP HORSEPOWER REQUIRED TO MEET FOLLOWING CONDITIONS. WHERE DO YOU PLACE PUMP?



$$HP + Z_A - Z_B = K_{en}\frac{V^2}{2g} + f\frac{L}{D}\frac{V^2}{2g} + K_{EX}\frac{V^2}{2g} = \frac{V^2}{2g}\left(K_{en} + K_{EX} + \frac{fL}{D}\right)$$

$$HP + 100 = \left[0.5 + 1.0 + \left((0.02)\frac{10000}{12/12}\right)\right]\frac{V^2}{2g} \Rightarrow Q = VA \rightarrow V = \frac{Q}{A}$$

$$V = \frac{6\,cfs}{\frac{\pi}{4}(1)^2} = \frac{24}{\pi} = 7.64\ FPS$$

$$HP = 82.6\ Ft$$

$$hp = \frac{\gamma Q HP}{550} = \frac{(62.4)\,6\,cfs\,(82.6')}{550} = 56.2\ HP$$

(lb/ft³)

BASED ON 0.80% EFFICIENCY $\frac{56.2}{0.80}$

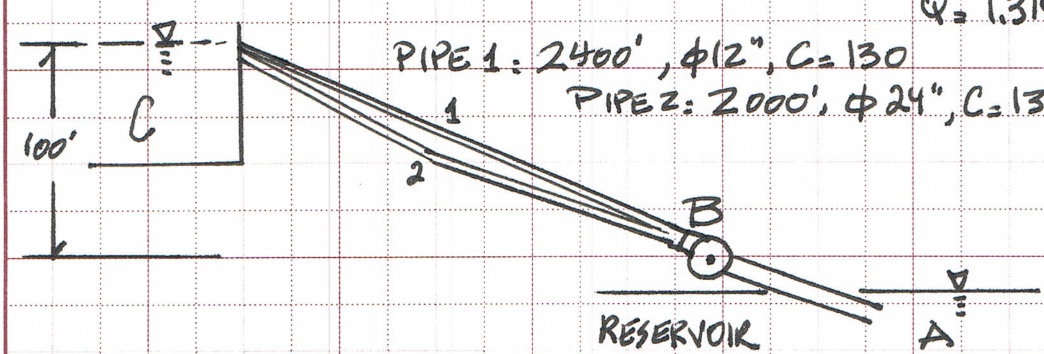
NEXT AVAILABLE SIZE TO BE SELECTED

FOR THE SITUATION BELOW PUMP ALLOWS WATER FROM RESEVOIR "A" TO "C". PUMP IS LOCATED AT B POSITION. TOTAL cfs of 40 IS CARRIED VIA 2-PARALLEL PIPES

WHAT IS PRESSURE AT B?

$Q = 1.318\, C A R^{0.63} S^{0.54}$

$S = \frac{h_f}{L(1000)}$



$C_1 = C_2$

PARALLEL PIPES $h_f = h_{f_1} = h_{f_2}$ & $Q = Q_1 + Q_2$

$h_f = \frac{4.73\, L_1}{C^{1.852} D_1^{4.87}} Q_1^{1.852}$ D & L in ft

$h_{f_1} = \frac{4.73\, L_1\, Q_1^{1.852}}{C^{1.852}\, D_1^{4.87}} = h_{f_2} = \frac{4.73\, L_2\, Q_2^{1.852}}{C^{1.852}\, D_2^{4.87}} \Rightarrow \frac{L_1}{L_2}\left(\frac{Q_1}{Q_2}\right)^{1.852}\left(\frac{D_2}{D_1}\right)^{4.87} = 1$

$\frac{2400}{2000}\left(\frac{Q_1}{Q_2}\right)^{1.852}\left(\frac{24}{12}\right)^{4.87} = 1$ & $40 = Q_1 + Q_2$

$Q_2 = 40 - Q_1$

FIND Q_1 & Q_2 → $Q_1 = 5.2$ Cfs; $Q_2 = 34.8$ Cfs

THEN FIND $h_{f_1} = f(L_1, C, D_1, Q_1) = 30$ Ft $= h_{f_2} = h_f$

TOTAL HEAD (NEGLECT MINOR LOSSES) = 30 + 100'

PRESSURE REQUIRED @ UPSTREAM OF PUMP @ "B"

$= 130'$ OR $P = \gamma H = 62.4 * 130 = 8112$ Psf

$= \frac{8112}{144} = 56.33$ Psi

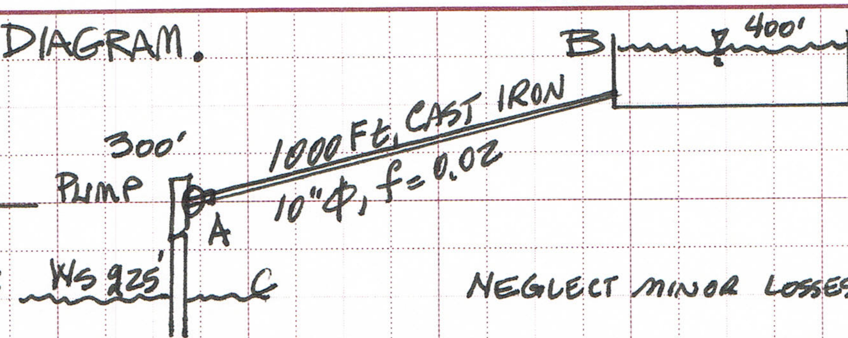
REVISIONS

SHEET NUMBER
JOB NAME:
RE:
DATE

DETAILS

ENGINEERING & CONSULTING

GIVEN FOLLOWING DIAGRAM.



PRESSURE GAGE
58 Psi =
$58 \times 144 = 8352$ Psf

NEGLECT MINOR LOSSES.

DETERMINE

a. PUMP DISCHARGE AT B GPM
b. η PUMP EFFICIENCY = 0.65. IF 6 HR / DAY OPERATION & 0.03 KWHR WHAT IS MONTHLY COST?

a.

$$\frac{P_A}{\gamma} + \frac{V_A^2}{2g} + Z_A = \frac{P_B}{\gamma} + \frac{V_B^2}{2g} + Z_B + h_L$$

$$\frac{8352}{62.4} + \frac{V_A^2}{2g} + 300' = \phi + \phi + 400 + h_L = 400 + \frac{f L V^2}{D\, 2g}$$

$$= 400 + 0.02 \frac{1000}{10/12} \frac{V_A^2}{2(32.2)} \rightarrow V = 9.75 \text{ fps}$$

$$Q = VA = 9.75 \frac{\pi}{4}\left(\frac{10}{12}\right)^2 = 5.32 \text{ Cfs} * 7.48 * 60 = 2380 \text{ GPM}$$

b. FROM C: TO B:

$$H_P + 225 + \frac{P_C}{\gamma} + \frac{V_C^2}{2g} = 400 + \phi + \phi + h_L$$

($P_C/\gamma \rightarrow 0$, $V_C^2/2g \rightarrow 0$)

$$H_P = 400 - 225 + \frac{0.02}{10/12}(1000 + 300 - 125)\frac{9.75^2}{(2)32.2}$$

$$= 213.1 \text{ Ft}$$

$$hp = \frac{\gamma Q H_P}{550\,\eta} = \frac{(62.4)\,5.32\text{CFS}\,(213.1)}{(0.65)(550)} = 197.9 \text{ hp}$$

$$= 197.9\,(746\text{W}) = 147 \text{ KW}$$

$$\$ = 147\,(30 * 6)\text{ KWH} * \$0.03/\text{KWH} = \$794.00$$

Absolute Consulting Engineers
Total Design and R&D Engineers
(949) 852-8700
Absoluteco.Com

REVISIONS

SHEET NUMBER 1

JOB NAME: HYDRAULICS

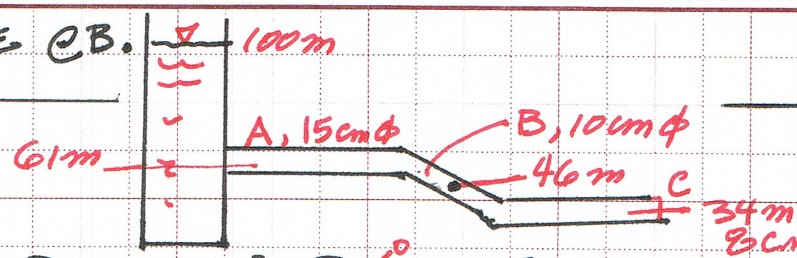
RE: BERNOULI

DATE 3/30/05

DETAILS

ENGINEERING & CONSULTING

FIND PRESSURE @B.



$P_C = \phi$ FREE JET

$V_A = \phi$ RESERVOIR

$P_A = \phi$

APPLY BERNOULI EQUATION

$$\frac{P_A}{\rho g} + Z_A + \frac{V_A^2}{2g} = \frac{P_B}{\rho g} + Z_B + \frac{V_B^2}{2g} = \frac{P_C}{\rho g} + Z_C + \frac{V_C^2}{2g} = Z_A = 100$$

(with $\frac{P_A}{\rho g}$, $\frac{V_A^2}{2g}$ and $\frac{P_C}{\rho g}$ crossed out as 0)

$$Z_A = 100 = \frac{P_B}{\rho g} + 46m + \frac{V_B^2}{2g} = 34 + \frac{V_C^2}{2g} \Rightarrow V_C = 36 m/s$$

$$V_C A_C = V_B A_B \qquad \text{CONTINUITY OF MASS}$$

$$(36 m/s)\left(\frac{\pi D_C^2}{4}\right) = V_B\left(\frac{\pi D_B^2}{4}\right)$$

$$36 D_C^2 = V_B D_B^2 \rightarrow V_B = 36\frac{D_C^2}{D_B^2} = 36\left(\frac{8}{10}\right)^2 = 23 m/s$$

$$\frac{P_B}{\rho g} + 46m + \frac{(23)^2}{2g} = 34 + \frac{(36)^2}{2g} = 100$$

$$\frac{P_B}{(998.23\frac{kg}{m^3})(9.8 m/s^2)\frac{N s^2}{kg \cdot m}\left(\frac{1 kN}{1000 N}\right)} + 46^m + \frac{(23)^2 m^2/s^2}{(2)9.81\frac{m}{s^2}} = 34m + \frac{36^2 m^2/s^2}{2(9.81 m/s^2)} = 100m$$

$$P_B = 265 \, KN/m^2$$

Absolute Consulting Engineers
Total Design and R&D Engineers
(949) 852-8700
Absoluteco.Com

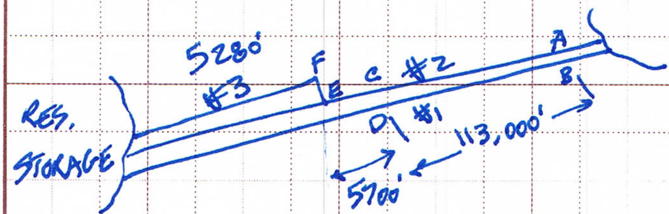
REVISIONS

SHEET NUMBER
JOB NAME: HYDRAULICS
RE:
DATE 9/15/05

DETAILS

ENGINEERING & CONSULTING

2 PIPES FEED STORAGE RESERVOIR. PIPE #2 IS EXTENDED & BYPASS THIRD PIPE 52,800 Ft. $Q_1 = 74$ mgd, $Q_3 = 61$ mgd



PRESSURE GAGE

POINT	ELEV. GAGE, Ft	GAGE READING Psi
A	192	207
B	26	179
C	23	170
D	397	3
E	192	215
F	26	198

HAZEN WILLIAMS $V = 1.318\, C R^{0.63} S^{0.54}$ $\quad S = \frac{h_L}{L}$ $\quad R = d/4$

HYDRAULIC GRADE LINE = $Z + \text{Psi} \frac{\#}{in^2} \cdot \frac{144\, in^2/ft^2}{62.4\, lb/ft^3}$

@ B ⇒ $192 + 215(144/62.4) = 688'$

@ D ⇒ $26 + 198(144/62.4) = 483'$

$205'$ $\quad \ell = 113{,}000$

$S^{0.54} = \left(205/113{,}000\right)^{0.54} = 0.0331$

$V_1 = \frac{Q_1}{A_1} = \frac{74(10^6)/24(3600)(7.48)}{(58/12)^2 \pi/4} = \frac{114.5\text{ CFS}}{A_1} = 6.23\text{ FPS}$

$R_1^{0.63} = \left(\frac{58}{12(4)}\right)^{0.63} = 1.127$ $\quad V = 6.23 = 1.318\, C(1.127)\, 0.0331 \Rightarrow C_1 = 127$

@ F ⇒ $23 + 170(144/62.4) = 416'$

@ G ⇒ $397 + 3(144/62.4) = 404'$

$h_L = 12'$

$\ell = 52{,}800'$; $S_3^{0.54} = \left(\frac{12}{52{,}800}\right)^{0.54} = 0.0108$

$Q_3 = 61\text{ mgd} = 94.4\text{ cfs}$; $R_3^{0.63} = \left(\frac{78}{4(12)}\right)^{0.63} = 1.358$

$V_3 = \frac{Q_3}{A_3} = \frac{94.4}{\pi/4\,(78/12)^2} = 2.84 = 1.318(1.358)(C)\,0.0108$ $\quad C_3 = 147$ ←

@ A → $192 + 207(144/62.4) = 670'$

@ C → $26 + 179(144/62.4) = 439'$

$\Delta h_L = 231'$

@ E → $439\big|_{@C} - \left(\frac{5700}{113\,000}\right)(670 - 439)\big|_{C\,to\,E} = 427.3'$

@ F → $23 + 170(144/62.4) = 416'$ $\quad = 416$

$11.3'$

36" φ CROSS CONNECTION

$V_x = V_3\left(\frac{d_3}{d_x}\right)^2 = 2.84\left(\frac{78}{36}\right)^2 = 13.3\text{ F/S}$

$\frac{V_x^2}{2g} = 2.75$; $h_L = 11.3 \Rightarrow \frac{h_L}{V^2/2g} = 11.3/2.75 \Rightarrow h_L = 4.11\, V_x^2/2g$

MAJORITY OF LOSSES ARE ENTRANCE & EXITS

EXISTING RESERVOIR IS FED FROM 825' ELEVATION WITH (2) PIPES (47 mi)
A THIRD PIPE INTERCEPTS PIPE #2 WITH 36"φ FOR 20' & THEN PARALLEL TO PIPE #2

NEGLECT MINOR LOSSES

	#1	#2	#3	CONNECTION
MILE	47	47	10 (10 MILES)	20 Ft
φ; "	58"	60"	78"	36"
f	0.013	0.012	0.012	0.012
LINING	MORTAR	ENAMEL	ENAMEL	ENAMEL

EXISTING $\Delta H = f\frac{\ell}{d}\frac{V^2}{2g} = 825-427 = 398'$

$V = \left(\frac{\Delta H\, 2g\, d}{\ell f}\right)^{1/2}$

$Q = AV = A\left(\Delta H 2gd/\ell f\right)^{1/2}$

$Q_1^2 = \left(\frac{\pi d_1^2}{4}\right)^2\left(\Delta H\, 2g\, d_1/\ell_1 f_1\right) \Rightarrow \Delta H = \frac{Q_1^2}{(\frac{\pi}{4}(d_1^2))^2}\frac{f_1\ell_1}{d_1 2g}$

$Q_1 = \frac{\pi}{4}\left(\frac{58}{12}\right)^2\left(\frac{398(58/12)64.4}{47(5280)(0.013)}\right)^{1/2} = 114\,cfs = 73.7\,mgd$

$\Delta H = \frac{Q_2^2}{(\frac{\pi}{4}d_2^2)^2}\frac{f_2\ell_2}{d_2 2g}$

$1 = \frac{Q_1^2}{Q_2^2}\frac{f_1\ell_1}{f_2\ell_2}\frac{d_2^5}{(d_1)^5}$

$1 = \frac{Q_1}{Q_2}\left(\frac{d_2}{d_1}\right)^2\sqrt{\frac{f_1}{f_2}\frac{d_2}{d_1}}$

$Q_2 = Q_1 \cdot \frac{d_2^2}{d_1^2}\sqrt{\frac{f_1}{f_2}\frac{d_2}{d_1}} = 73.7\left(\frac{60}{58}\right)^{5/2}\left(\frac{0.013}{0.012}\right)^{1/2} = 83.3\,mgd$

NEW FOR 10 MILES (a) $Q_2 = Q_{2a} + Q_{2b}$; $h_a = h_b$

$\frac{\pi d_2}{4}V_2 = \frac{\pi d_a^2}{4}V_a + \frac{\pi d_b}{4}V_b \quad d_b = d_2;$

$V_2 d_2^2 = V_a d_a^2 + V_b d_b^2$

(1) $V_2 = V_a\left(\frac{d_a}{d_b}\right)^2 + V_b$

(b) $h_a = h_b = f_a\frac{\ell_a}{d_a}\frac{V_a^2}{2g} = f_b\frac{\ell_b}{d_b}\frac{V_b^2}{2g} =$

(2) IF $f_a \doteq f_b \Rightarrow V_a^2 = \frac{d_a}{d_b}V_b^2$

USE (b) FOR ORIGINAL RUN

$f_2\frac{\ell_2}{d_2}\frac{V_2^2}{2g} + f_b\frac{\ell_b}{d_b}\frac{V_b^2}{2g} = 398'$

(3) $\frac{\ell_2}{\ell_b}V_2^2 + V_b^2 = \frac{2gd_b}{f\ell_b}398$

SOLVING (1), (2), & (3)

$V_2 = 2.92 V_b$; $V_a = 2.84\,FPS$

$Q_b = \frac{\pi}{4}\left(\frac{60}{12}\right)^2 2.49 = 48.9\,cfs = 31.6\,mgd$

$Q_a = \frac{\pi}{4}(78/12)^2(2.84) = 94.3\,cfs = 61.0\,mgd$

$Q_2 = Q_a + Q_b = 92.6\,mgd$

VELOCITY IN 36" PIPE (20' ONLY)

$V_x = \left(\frac{d_a}{d_x}\right)^2 V_a = \left(\frac{78}{36}\right)^2 2.84 = 13.3\,Ft/s$

HEAD LOSS THROUGH 36" PIPE, 20 Ft

$h_L = f\frac{\ell}{d}\frac{V^2}{2g} = 0.012\left(\frac{20}{3}\right)\left(\frac{13.3^2}{64.4}\right) = 0.22'$

$398' \gg 0.22$ ∴ NEGLIGIBLE.

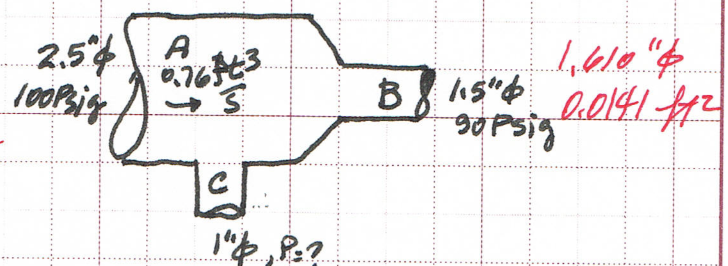
Absolute Consulting Engineers
Total Design and R&D Engineers
(949) 852-8700
Absoluteco.Com

REVISIONS

SHEET NUMBER 1
JOB NAME: HYDRAULICS
RE:
DATE 3/25/05

DETAILS | ENGINEERING & CONSULTING

WATER FLOWING IN A SCHEDULE 40 STEEL PIPE AS SHOWN.
WHAT IS FLOW RATE @ C?



$E_A = E_B$

$$\frac{P_A}{\gamma} + Z_A + \frac{V_A^2}{2g} = \frac{P_B}{\gamma} + Z_B + \frac{V_B^2}{2g} \quad (Z_A = 0,\ Z_B = 0)$$

$$\frac{100\ Psi\ 144\ in^2/ft^2}{62.4\ lbf/ft^3} + \frac{V_A^2}{2g} = \frac{90\ Psi\ 144}{62.4} + \frac{V_B^2}{2g}$$

$$(100-90)\frac{144}{62.4} = (V_B^2 - V_A^2)/2g =$$

$$\frac{1440}{62.4}(2)(32.2) = V_B^2 - 23^2 \Rightarrow V_B = 45\ ft/s$$

$Q_A = V_A A$

$0.76\ \frac{ft^3}{s} = V_A\ 0.0332$

$V_A = 23\ ft/s$

$$\dot{m}_A = \dot{m}_B + \dot{m}_c = \rho_A V_A A_A = \rho_B V_B A_B + \rho_c V_c A_c$$

$$V_A A_A = V_B A_B + V_c A_c$$

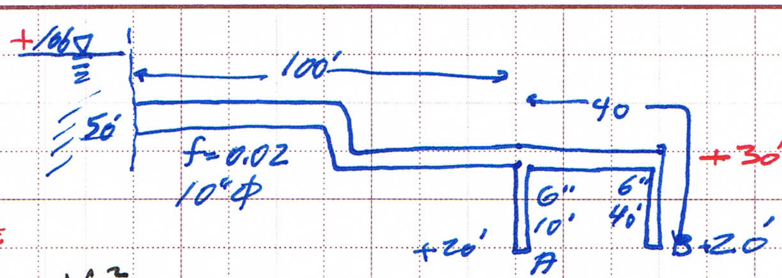
$$(0.0332)23 = (0.0141)(45) + (0.006) V_c$$

$$V_c = 22\ ft/s$$

$$Q = V_c A_c = (22)(0.006) = 0.13\ ft^3/s$$

INSTALLATION SHOWN

WHAT IS Q_A OR Q_B ?



PATH 10"φ → 6"A → DISCHARGE

$$-f\frac{L_A}{D_6}\frac{V_{10}^2}{2g} + 80 - f\frac{L_{10}}{D_{10}}\frac{V_{10}^2}{2g} + \phi = \frac{V_A^2}{2g} + 20$$

$$+f\frac{L_B}{D_6}\frac{V_{10}^2}{g} + 80 - f\frac{L_{10}}{D_{10}}\frac{V_{10}^2}{2g} + \phi = \frac{V_B^2}{2g} + 20$$

$$f\left(\frac{L_A}{D_6} + 1\right)V_A^2 = f\left(\frac{L_B}{D_6}\right) + 1 V_B^2$$

$$V_A = \left(\frac{fL_B + D_6}{fL_B + D_6}\right)^{1/2} V_B = 1.365\, V_B$$

$V_A = 1.365\, V_B$

ARE A / MASS $\left(V_{10}\right)\frac{D_{10}^2\pi}{4} = \Sigma\, F_{FLOW\,IN} = \Sigma\, F_{OUT} = V_{10}\frac{\pi}{4}D_{10}^2 = V_A\frac{\pi D_6^2}{4} + V_B\frac{\pi D_6^2}{4}$

$$V_{10} = \left(\frac{6}{10}\right)^2 (V_B + 1.36 V_B) = 0.853\, V_B$$

$V_{10} = 0.853\, V_B$

$$\left(f\left(\frac{L_A}{D_6}\right) + 1\right) V_B^2 (1.365)^2 = \left(f\left(\frac{L_B}{D_6}\right) + 1\right) V_B^2$$

TO CHECK ?

$$80 - f\frac{L_{10}}{D_{10}}\frac{V_{10}^2\ (0.835\,V_B)^2}{2g} - f\frac{L_B}{D_6}\frac{V_B^2}{2g} = \frac{V_B^2}{2g} + 20 \Rightarrow (60)2g = \left(\left[f\frac{L_{10}}{D_{10}}(0.853)^2 + \frac{L_B}{D_6}\right] + 1\right) V_B^2$$

$$V_B^2 = 60(2)(32.2) \Big/ \left(\left[0.02\left(\frac{100}{10/12}(0.853)^2 + 40/(6/12)\right)\right] + 1\right)$$

$$= 890\,(FPS)^2$$

$V_B = 29.8$ FPS

$V_{10} = 0.853\, V_B$

$V_{10} = 26.4$ Ft/s

$$Q = A_{10} V_{10} = \frac{\pi}{4}\left(\frac{10}{12}\right)^2 26.4$$

$Q = 13.85\ Ft^3/s$

5CFS, SCH.40 S.S. PIPE 6" @ POINT A TO 18" POINT B. $P_A = 10$ Psia, $P_B = 7$ Psia
WHAT IS DIRECTION & VELOCITY? B = 15' ABOVE

SCH 40, $D_A = 0.5054$ Ft; $D_B = 1.4063$ Ft, $Z_A = \phi$ $E_{tA} = E_P + E_V + E_Z = \frac{P_A}{\rho} + \frac{V_A^2}{2g_c} + \frac{Z_A g}{g_c}$

$E_{tB} = \frac{P_B}{\rho} + \frac{V_B^2}{2g_c} + \frac{Z_B g}{g_c}$

$E_{tA} = 10\frac{lbf}{in^2}\left(144\frac{in^2}{Ft^2}\right) / 62.4\frac{lbm}{ft^3} + \frac{5\ CFS}{0.5054\ ft^2 (\pi/4)(2g_c)} + \phi = \frac{7Psi\left(144\frac{in^2}{ft^2}\right)}{62.4\frac{lbm}{ft^3}} + \frac{5\ CFS}{(1.4063)^2 ft^2\ \pi/4\ (2g_c)} + \frac{15(32.2)}{32.2}$

$32.7\ \frac{Ft\text{-}lbf}{lbm} > 31.3\ Ft\text{-}lbf/lbm$

∴ FLOW A TO B.

POINT A TO B = 3000 Ft, 6" SCH. 40 STEEL @ 60' ABOVE A. $P_B = 50$ Psig; $P_A = ?$
750 GPM @ 60°F

$Re = \frac{VD}{\nu} = \frac{(\dot V/A)D}{\nu} = \frac{(\dot V/\pi D^2/4)D}{\nu} = \frac{4\dot V}{\pi D \nu} = \frac{4(750GPM * 0.002228\ Ft^3\text{-}min/sec\text{-}gal)[Ft^3/s]}{\pi(0.5054)Ft\ 1.217\times10^{-5}\ Ft^2/sec} = 3.46\times10^5$

STEEL $\epsilon = 0.0002$ $\epsilon/D = 0.0002/0.5054 = 0.0004$ $f = 0.0175$

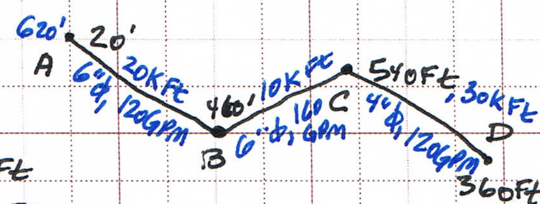
$h_f = \frac{fLV^2}{2Dg_c} = 0.0175(3000Ft)(8.33\ Ft/s)^2 / 2(0.5054\ Ft)(32.2\ Ft/s) = 111.9\ Ft$

$\frac{V_1^2}{2g} + Z_1 + \frac{P_1}{\rho} = \frac{V_2^2}{2g} + Z_2 + \frac{P_2}{\rho} + h_f$ $V_1 = V_2$, $Z_1 = 0$

$\frac{P_1}{\rho} = Z_2 - Z_1 + \frac{P_2}{\rho} \Rightarrow \frac{144}{62.37}\frac{in^2}{Ft^2}\ \frac{P_1}{lbf/ft^3} = \frac{50\frac{lbf}{in^2}}{62.3\frac{lbm}{ft^3}}\left(144\ in^2/Ft^2\right) + 60 + 119$

$P_1 = 124.5\ lbf/in^2$

PIPE NETWORK A, B, C, D. C = 150. 20 Psig MIN PRESSURE



$h_{fA\text{-}B}$

$\frac{10.44(L)(GPM)^{1.85}}{C^{1.85}(D_{in})^{4.8665}} = \frac{10.44(20000)(120)^{1.85}}{(150)^{1.85}(6)^{4.8665}} = 22.6\ Ft$

$h_{fB\text{-}C} = 10.44(10000)(160)^{1.85}/(150)^{1.85}\ 6^{4.8655} = 19.25\ Ft$

$h_{fC\text{-}D} = 10.44(30000)(120)^{1.85}/(150)^{1.85}\ 4^{4.8566} = 243.9\ Ft$

$h_{pA} + Z_A = h_{pB} + Z_B + h_{fA\text{-}B} = 20Psi)_A\frac{(144)}{62.4} + 620\ Ft = h_{pB} + 460Ft + 22.6Ft \rightarrow h_{pB} = 183.6Ft$

$h_{pB} + Z_B = h_{pC} + Z_C + h_{fB\text{-}C} = 183.6 + 460 = h_{pC} + 540Ft + 19.25$ ∴ $h_{pC} = 84.35' = 36.6$ Psi $P_B, Yh = 79.6$ Psi

$h_{pC} + Z_C = h_{pD} + Z_D + h_{fCD} = 84.35 + 540 = h_{pD} + 360 + 243.9$; $h_{pD} = 20.45 = 8.9$ Psi

SINCE MIN ALLOWABLE PRESSURE IN SYSTEM = 20Psi 20 − 8.9 = 11.1 #/in²

∴ $P_A = 20Psi - 8.9Psi = 11.1$ #/in² ∴ $P_A = 20 + 11.1$ Psi = 31.1 Psi

$P_B = 79.6 + 11.1 = 90.7$ Psi ; $P_C = 36 + 11.1 = 47.7$, $P_D = 8.9 + 11.1 = 20$ Psi

$h_{AD} = Z_A - Z_D + \frac{P_A - P_D}{\gamma} = 620' - 360' + \frac{(31.1 - 20)(144)}{62.4} = 285.6$

٢٨

Absolute Consulting Engineers
Total Design and R&D Engineers
(949) 852-8700
Absoluteco.Com

REVISIONS

SHEET NUMBER 11
JOB NAME: HYDRAULICS
RE:
DATE 3/30/05

DETAILS — ENGINEERING & CONSULTING

PUMP ELEVATES WATER FROM 457 Ft to 503 Ft WITH 500 Ft OF 2" ∅ SCH. 80 PVC PIPE @ 5 Ft/s. THERE ARE 15 COUPLES, (8) 90° ELBOWS, (4) 45° ELBOWS, (6) Tees STRAIGHT FLOW & (2) GLOBE VALVES. ALL FITTINGS ARE STANDARD PIPE THREAD. WATER IS @ 60°F. WHAT IS TOTAL HEAD LOSS FROM ALL SOURCES?

HEAD LOSS FROM: ELEVATION + LOSS THRU PIPES

$$= (Z_2 - Z_1) + h_f = \Delta Z + f \frac{(L+Le)\, V^2}{2Dg}$$

$$= (503 - 457) + f \frac{(500 + Le)(5)^2}{(2)\left(\frac{1.939}{12}\right)(32.2)}$$

$V = 5$ Ft/s
$D = 2''$ PVC
$\Delta Z = 46$ Ft
$L = 500$ Ft
$D = 1.939$ in

NEED $f = F\left(\frac{\epsilon}{D}, Re, D, \ldots\right)$ → $Re = \frac{Dv}{\nu}$ → $\frac{\epsilon}{D}$ ROUGHNESS

2" SCH. 80 PVC; $\epsilon = 0.000005$ Ft → $\frac{\epsilon}{D} = \frac{0.000005\,(12)}{1.939} = 0.000{,}031$

$$Re = \frac{Dv}{\nu} = (1.939)\left(\tfrac{1}{12}\right)(5\text{ Ft/s}) / (1.217 \times 10^{-5}\text{ Ft}^2/\text{s}) = 6.6 \times 10^4$$

$$f = \frac{0.25}{\left(\log\left(\frac{\epsilon/D}{3.7} + \frac{5.74}{Re^{0.9}}\right)\right)^2} = 0.25 \Big/ \left[\log\left(\frac{0.000031}{3.7} + \frac{5.74}{(6.6\times10^4)^{0.9}}\right)\right]^2 = 0.0197$$

FITTING	Q.	EQ. Ft.	TOTAL Ft
COUPLE	15	0.45	6.75
90° ELL	8	3.1	24.8
45° ELL	4	2.7	10.8
St. Tee	6	7.7	46.2
GLOBE V.	2	54	108
			196.55

$$\text{Head Loss} = 46 + (0.0197)\frac{(500 + 196.55)}{2\left(\frac{1.939}{12}\right)32.2} = 79 \text{ Ft}$$