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REVISIONS

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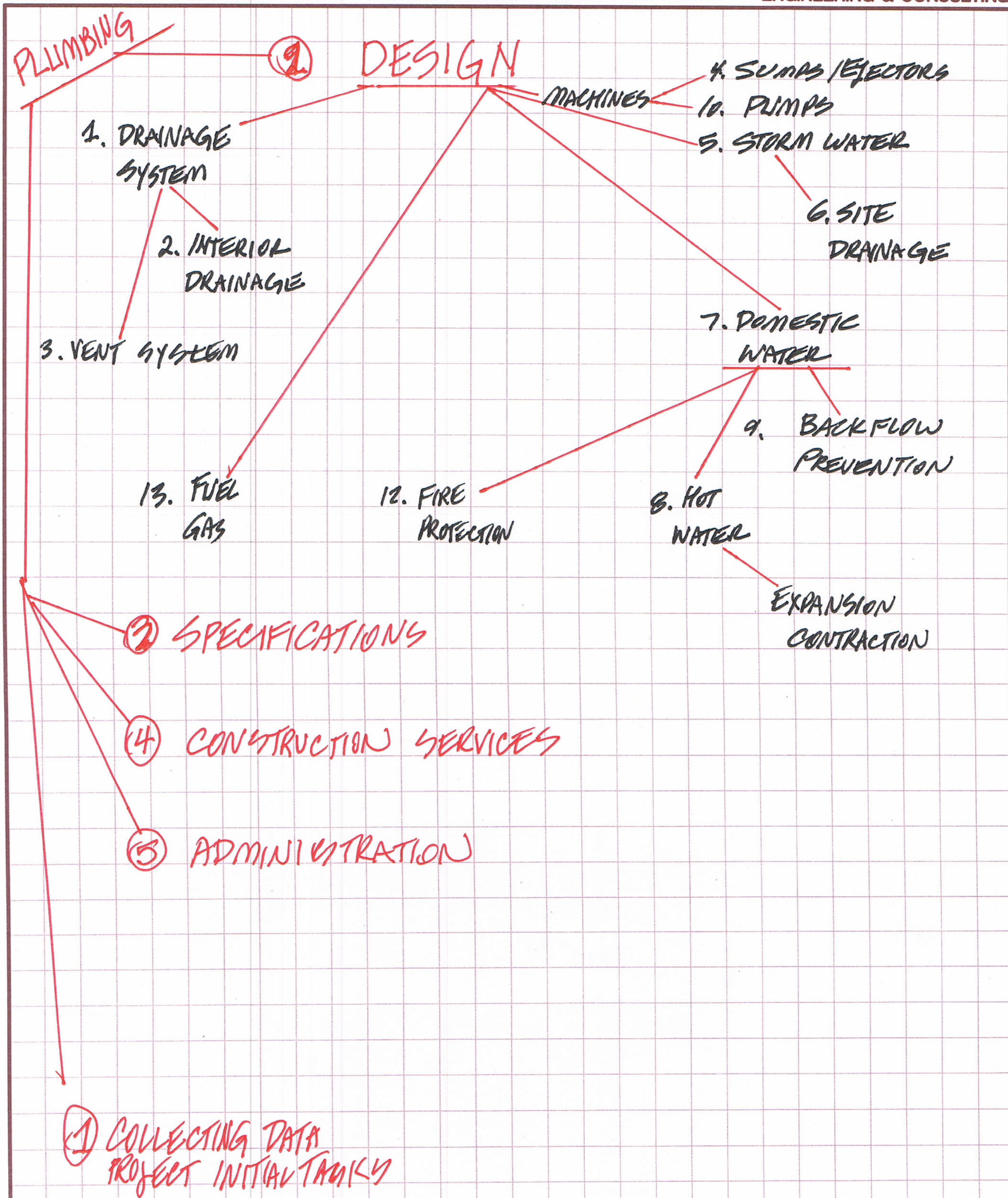
RE: ______

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



HYDRAULICS/HYDROLOGY/CLIMATOLOGY

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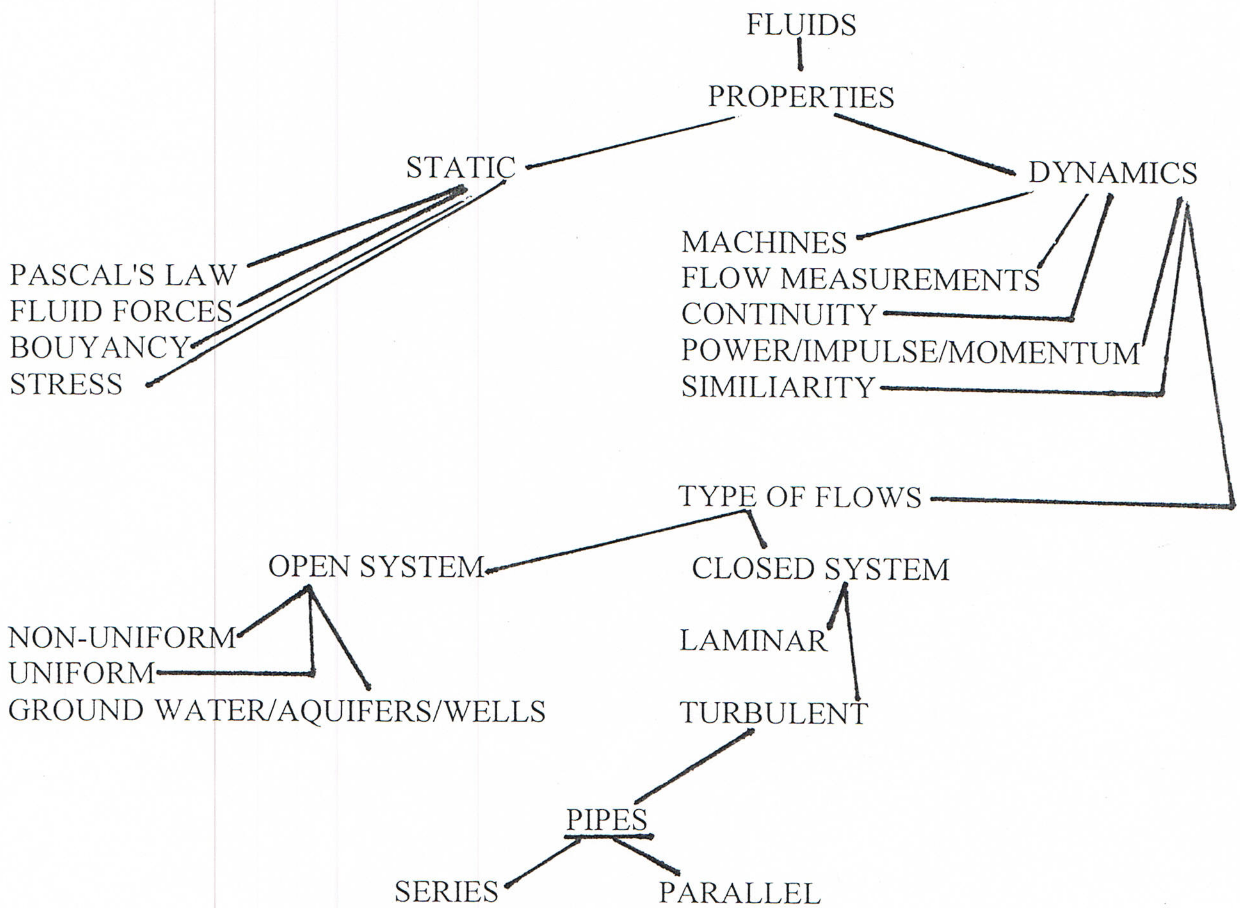
- Preparation Issues
  - SUBJECTS/CONCEPTS- Conservation: mass, momentum, energy, Bernoulli
  - UNITS/CONVERSIONS
  - INFORMATION FROM DATA BOOKS
  - EXERCISE/EXERCISE/EXERCISE



TYPE OF PROBLEMS
1957 - PRESENT

- STATIC FORCES ON PLANE
- BOUYANCY
- STRESSES ON CYLINDER- MIXED WITH STATIC FORCES

- BASIC BERNOULLI ISSUES
- IMPULSE/MOMENTUM
- EGL AND HGL
- LAMINAR/TURBULENT
- DARCY WEISBACH/MANNING/HAZEN WILLIAMS/MOODY DIAGRAM
- LOSSES THRU SYSTEM- SURFACES, PIPES, ETC.
- PIPES: PARALLEL, SERIES, NETWORK
- PUMPS: SINGLE, SERIES, PARALLEL
- COST ISSUES AND PUMP SELECTION
- NPSH, CAVITATION, PLACEMENT, SELECTION
- MATERIAL SELECTION
- FLOW MEASUREMENTS
- VALVES

- OPEN CHANNEL
- BASIC ISSUES: HGL,EGL
- GEOMETRIES OF FLOW
- MATERIAL SELECTION AND EFFECT
- CRITICAL/SUBCRITICAL/SUPERCRITICAL
- HYDRAULIC JUMP AND DROP
- CHEZY/MANNING FORMULA
- CULVERT DESIGN

- FLOW MEASUREMENTS

- SIMILITUDE

- GROUND WATER HYDRAULICS

- HYDROLOGY CYCLE
- STORM CHARACTERISTICS- TIME OF CONCENTERATION
- RAINFALL INTENSITY
- HYDROGRAPH- UNIT
- SYNTHETIC UNIT
- RATIONAL METHOD
- NATURAL RESOURCES CONSERVATION SERVICES CURVE NUMBER
- RESERVOIR SIZING
- WATER MANAGEMENT MODELING

- GROUNDWATER AQUIFER
- WELL DRAWDOWN

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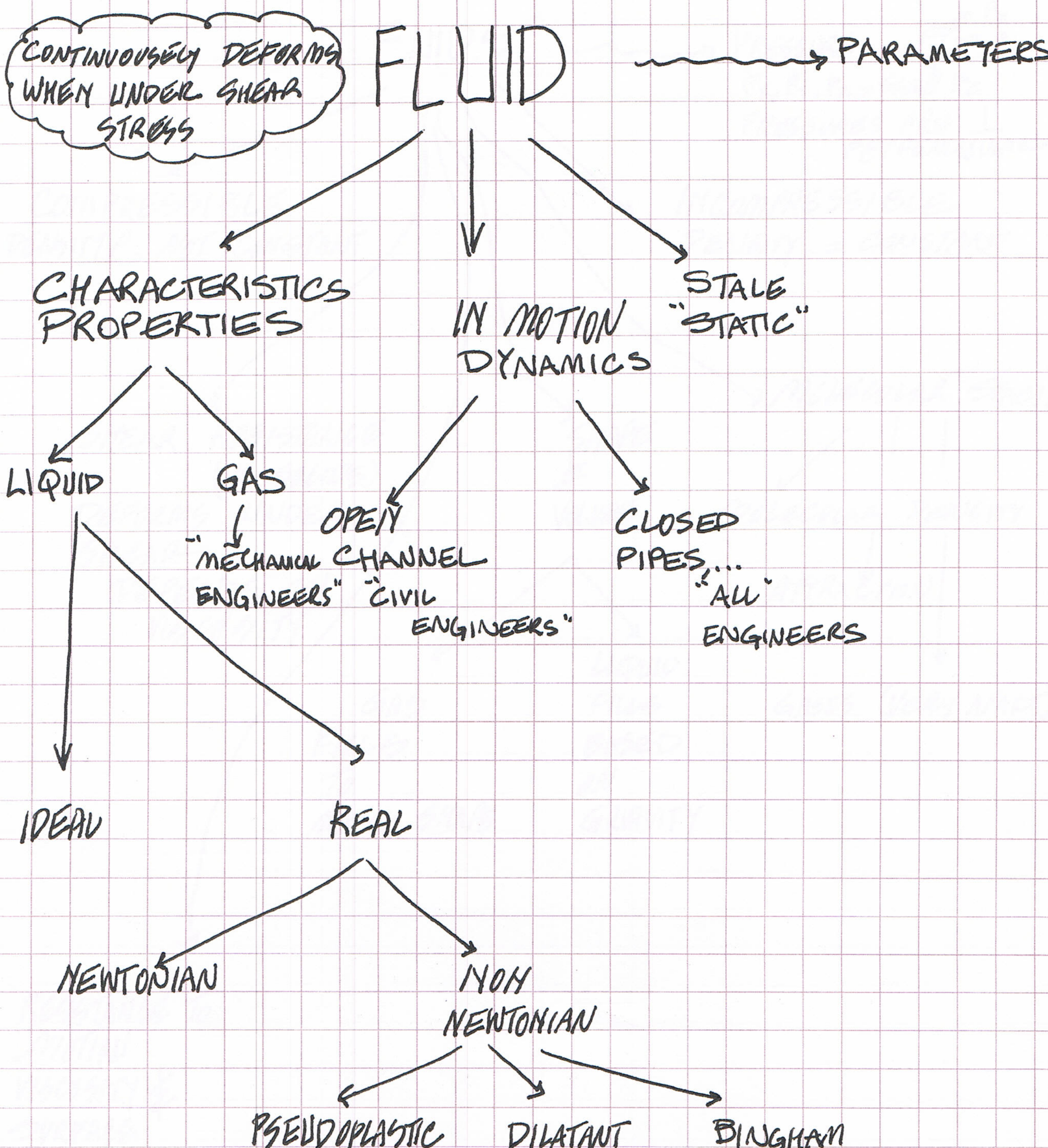

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SPECIFIC ~

SPECIFIC VOLUME: $v = 1/\rho = m^3/Kg$

SPECIFIC GRAVITY: SG_{liq} DENSITY OF FLUID / DENSITY of H_2O

SG_{gas} DENSITY OF GAS / DENSITY of AIR

LIQUID = DENSITY of MATERIAL (OIL, ...) / DENSITY of WATER $\frac{1000\ Kg}{m^3}$

$= (10^{-3}) * {}^{MAT.}Kg/m^3 * m^3/Kg = (0.001)(\rho_{MATERIAL}) =$ UNITLESS

SPECIFIC GRAVITY OF GAS: $\rho_{gas}/\rho_{AIR} = \frac{MW_{GAS}}{MW_{AIR}} = \frac{MW_{GAS}}{29.0} = \frac{R_{AIR}}{R_{GAS}} = \frac{53.3}{R_{GAS}}$

$\rho = P/RT$ $\quad T_1 = T_{AIR}, P_1 = P_{AIR}$

$\rho_1/\rho_{AIR} = P_1/R_1T_1 \big/ P_{AIR}/R_{AIR}T_{AIR} = \frac{R_{AIR}}{R_1}$

STANDARD TEMPERATURE & PRESSURE

SI SYSTEM	273.1 °K	101.325 KPa PRESSURE
SCIENTIFIC	0.0 °C	760 mm Hg
NATURAL gas (CA)	60 °F	
NATURAL Gas (US)	80 °F	14.65 Psia, 14.73 or 15.02 Psia
US ENGINEERING	0°C = 32°F	14.696 Psia

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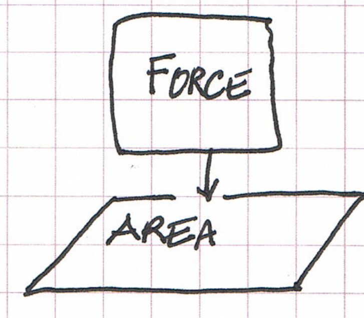
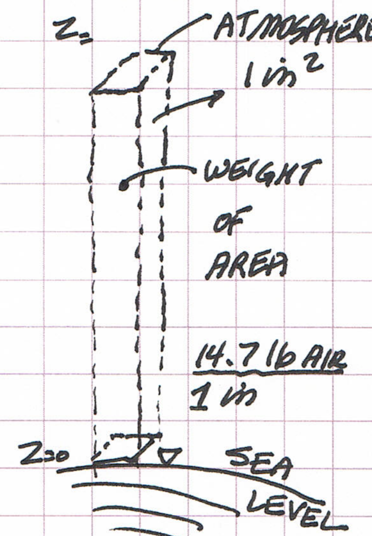
PRESSURE



FORCE / AREA = PRESSURE

PRESSURE OF AIR @ SEA LEVEL
WEIGHT OF AIR WITHIN 1"x1"x Z = 14.7#
CALLED STP
STANARD TEMPERATURE / PRESSURE
@ SEA LEVEL



STP

14.696 lb PER SQ. INCH "ABSOLUTE"
1.000 ATMOSPHERE
407.1 in W.g. INCHES OF WATER, INCHES H_2O GAGE
33.93 ft W.g. FEET OF WATER, FEET WATER GAGE

29.921 in Hg INCHES OF MERCURY
760 mm Hg millimeters of mercury
760 TORR

1.013 BARS
1013 MILLIBARS
1.013×10^5 Pa PASCAL

101.3 KILO PASCALS

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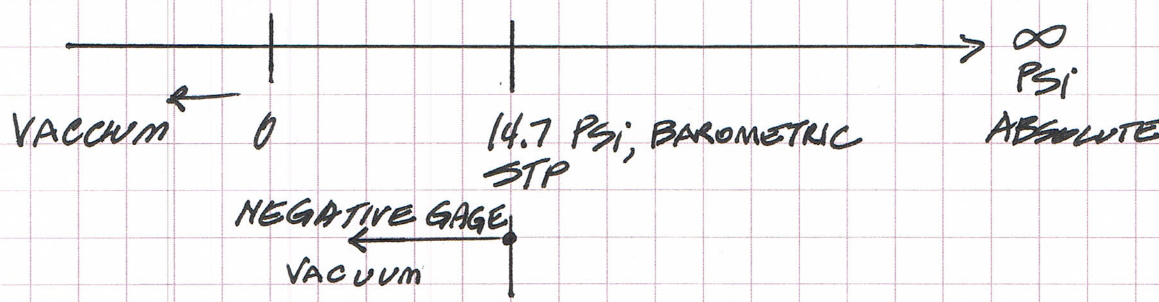
PRESSURE vs VACUUM

UNDER FORCE   UNDER SUCTION



$P_{ABSOLUTE} = P_{gage} + P_{ATMOSPHERIC}$

- CONTAINER UNDER VACUUM of 6 PSI
- GAGE PRESSURE MEASURED = 14.7 - 6 = 8.7 PSI gage MEASURED
- PRESSURE GAUGES: READ AMOUNT BEYOND ATMOSPHERIC PRESSURE

  15 PSI MEASURED = 15 PSI + 14.7 PSI = 29.7 PSI <u>ABSOLUTE</u>

- IF ΔP (PRESSURE CONDITION 1 - PRESSURE CONDITION 2) ATMOSPHERIC PRESSURES CANCEL OUT

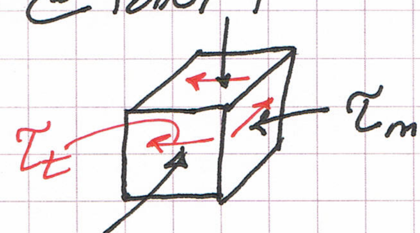
STRESS, τ

$\tau(P)$ = SURFACE STRESS VECTOR @ P_{POINT}

ΔF = FORCE ACTING ON INFITESIMAL AREA ΔA,

ΔA = INFINITESIMAL AREA @ POINT P

$\tau(P) = \lim_{\Delta A \to 0} \Delta F / \Delta A$ @ POINT P



τ_n = NORMAL STRESS @ P

τ_t = TANGENTIAL STRESS

$\tau_n = -p$, PRESSURE @ POINT P

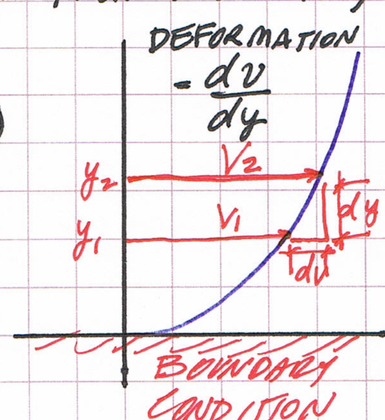
$\tau_t = \mu\,(dv/dy) = \left(\text{ABSOLUTE DYNAMIC VISCOSITY of FLUID}\right)\left(\dfrac{\text{VELOCITY@B.C.}}{\text{NORMAL DISTANCE}}\right)$

NEWTON'S LAW OF FRICTION OR VISCOSITY

dv = VELOCITY AT BOUNDARY CONDITION (B.C.)

dy = NORMAL DISTANCE, MEASURED FROM BOUNDARY

μ = ABSOLUTE DYNAMIC VISCOSITY (MEAURE OF VISCOSITY of FLUID)

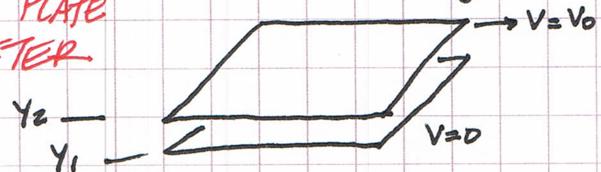


VISCOSITY

NEWTON'S LAW of VISCOSITY

$$\tau = \mu \frac{dv}{dy} = \frac{F}{A}$$

SLIDING PLATE VISCOMETER



$\Delta V = V_0$

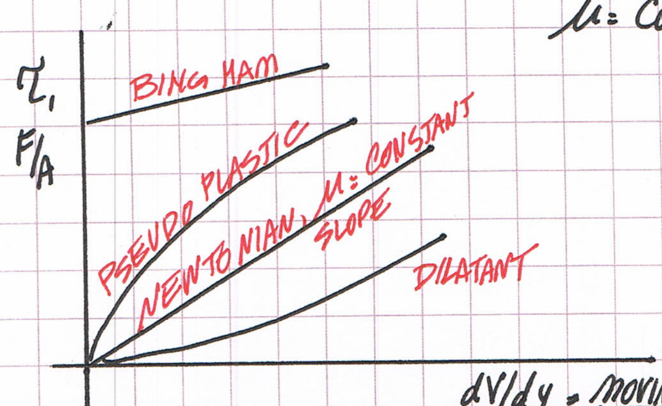
$\Delta y = Y_2 - Y_1$

FORCE REQUIRED HIGHER FOR HONEY THAN WATER

μ: ABSOLUTE "DYNAMIC" VISCOSITY = COEFFICIENT OF VISCOSITY

$\frac{dv}{dy}$: RATE OF STRAIN, SHEAR RATE, VELOCITY GRADIENT, RATE OF SHEAR DEFORMATION

NEWTONIAN FLUID = ν, μ VISCOSITY DOES NOT CHANGE & CHANGE IS LINEAR τ vs $\frac{dv}{dy}$
μ = CONSTANT SLOPE



$dV/dy = \frac{\text{MOVING OF PLATE VELOCITY } V_0}{\text{DISTANCE BETWEEN PLATES } \Delta Y_0}$

PSEUDOPLASTIC: MUDS, MOTOR OILS, POLYMER SOLUTIONS, GUMS, SLURRIES

BINGHAM: BINGHAM PLASTICS: TOOTH PASTE, JELLIES, BREAD DOUGH
INFINITE RESISTANCE TO SMALL SHEAR
MOVE EASILY DURING LARGER STRESS

DILATANT: WITH INCREASING VELOCITY, THE VISCOSITY INCREASES

THIXOTROPIC: VISCOSITY DECREASES WITH TIME

RHEOPECTIC: VISCOSITY INCREASES WITH TIME

TEMPERATURE: DECREASE IN VISCOSITY IN LIQUID & INCREASES μ in GASES

VAPOR PRESSURE

VAPOR PRESSURE OR SATURATION PRESSURE = WHEN MOLECULAR ACTIVITY IN LIQUID PERMITS VAPORIZING OF LIQUID SURFACE

OR VICE VERSA
IT CONDENSES BACK TO LIQUID

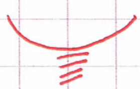
VOLATILE LIQUIDS: PROPANE, BUTANE, AMMONIA, FREON
SIGNIFICANT VAPOR PRESSURE @ NORMAL TEMPERATURES
LIQUIDS WHICH ARE NEAR BOILING POINT OR VAPORIZE NEAR NORMAL TEMPERATURES

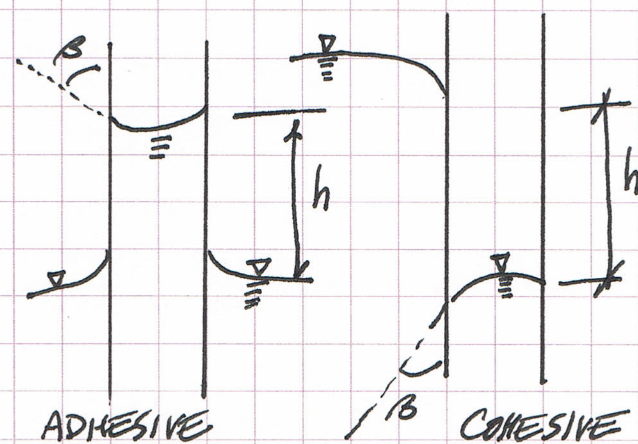
BOILING: WHEN TEMPERATURE INCREASES TO VAPOR PRESSURE IS EQUAL LOCAL AMBIENT PRESSURE
(a) LOCAL AMBIENT PRESSURE (b) TENDENCY TO VAPORIZE

COX CHART: VAPOR PRESSURE NONLINEAR RELATION WITH TEMPERATURE

FLUID	68°F, lbf/ft^2	20°C KPA
MERCURY	0.00362	0.000173
TURPENTINE	1.115	0.0534
WATER	48.9	2.34
ETHYL ALCOHOL	122.4	5.86
ETHER	1231	58.6
BUTANE	4550	218
FREON 12	12,200	584
PROPANE	17,900	855
AMMONIA	18,550	888

CAPILLARY ACTION = SURFACE TENSION OF LIQUID & SOLID SURFACE

- BEHVIOR OF LIQUID IN THIN_BOR TUBE
- ADHESION WITH SURFACE > COHESION OF MOLECULES
-  CURVED SURFACE = MENICUS
- IF DIAMETER ~< 0.1 inch



$r_{menicus} = r_{tube}$

- IN MERCURY = COHESIVE MOLECULAR FORCE > ADHESIVE
- $\beta > 90°$ = COHESIVE FORCE DOMINATES
  $\beta < 90°$ = ADHESIVE FORCES DOMINATE

β angle of CONTACT

MERCURY GLASS	140°
WATER - PARAFFIN	107°
WATER - SILVER	90°
KEI	
KEROSENE - GLASS	26°
GLYCERIN - GLASS	19°
WATER - GLASS	0°
ETHYL ALCOHOL, GLASS	0°

$$h = \frac{4\sigma\cos\beta}{\rho\, d_{tube}\, g} = \frac{4\sigma\cos\beta}{\rho d_{tube}}\left(\frac{g_c}{g}\right) = \frac{4\sigma\cos\beta}{\rho\, d_{tube}\, g}$$

$$\sigma = \frac{h \rho\, d_{tube}\, g}{4\cos\beta} = h \rho\, d_{tube}\, g / 4\cos\beta$$

$$= \frac{h \rho\, d_{tube}}{4\cos\beta}\, g/g_c$$

$r_{menicus} = r_{tube}$; $\beta = 0°$, $\cos\beta = 1.0$

if capillary < 0.1 in $\beta = 0°$

KINEMATIC VISCOSITY $\nu = \frac{\mu}{\rho}$

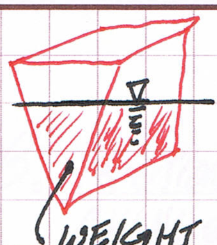
ν = KINEMATIC VISCOSITY = ABSOLUTE VISCOSITY / MASS DENSITY

$= \frac{\mu}{\rho} = \mu g_c / \rho$

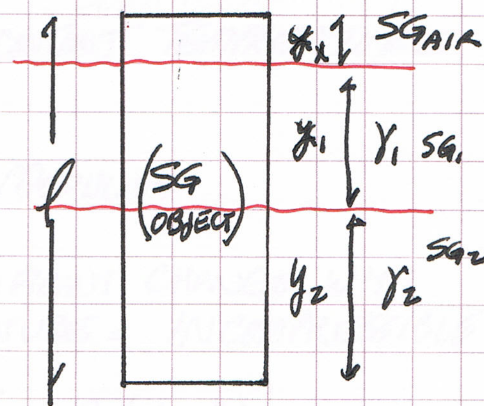
UNITS		
μ (ABSOLUTE)	ν (KINEMATIC)	
lbf-SEC / Ft^2 SLUG / Ft.SEC	Ft^2/SEC	BRITISH
DYNES.S / Cm^2 (POISE)	Cm^2/SEC (STOKE)	METRIC
Pa.S N.S/m^2	m^2/SEC	SI

BOUYANCY

$F_B = \gamma \, V_{\text{VOLUME DISPLACED}}$



WEIGHT EQUIVALENT OF VOLUME OF WATER DISPLACED = F_{BOUYANCY} UPWARD

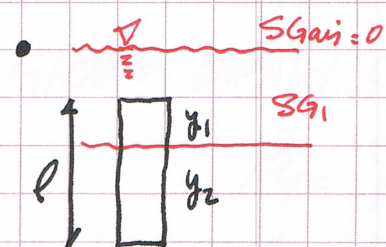


$$(SG)_{\text{OBJECT}} = \frac{W_{\text{DRY}}}{W_{\text{DRY}} - W_{\text{SUBMERGED}}}$$

$$SG\Big|_{\text{OBJECT}} = y_1(SG_1) + y_2(SG_2)$$

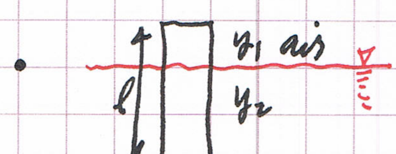
$SG_{air} \doteq \phi$

$$= (\ell - y_x - y_2)(SG_1) + y_2(SG_2) = y_1 SG_1 + (\ell - y_x - y_1)(SG_2)$$



$\ell = y_1 + y_2$

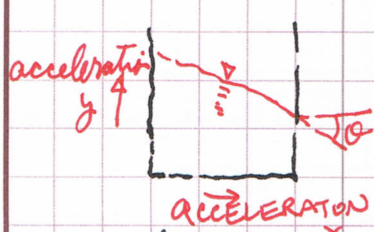
$$y_1 = \frac{SG_2 - SG_{\text{OBJECT}}}{SG_2 - SG_1} \; ; \; y_2 = \ell - y_1$$



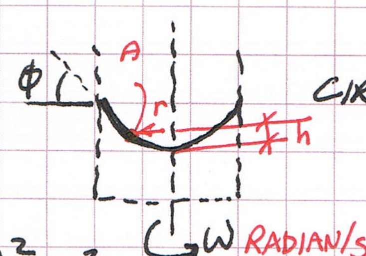
$$y_2 = \frac{SG_{\text{OBJECT}}}{SG_2}$$

$y_1 = \ell - y_1$

MOTION:



TRANSLATION



CIRCULAR

$p = \gamma h (1 + a_y/g)$

$\phi = \arctan(a_x / (a_y + g))$

$$h = \frac{(\omega r)^2}{2g} = \frac{V^2}{2g} \qquad \phi = \arctan\left(\frac{\omega^2 r}{g}\right)$$

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BULK MODULUS, E ~MODULUS OF ELASTICITY

SECANT BULK MODULUS

$$E = \frac{STRESS}{STRAIN} = \frac{-\Delta P}{\Delta V / V_0} = \frac{\text{INCREASE IN STRESS}}{\text{VOLUMETRIC STRAIN}}$$

~ SIMILIAR TO HOOKS LAW

$$= -V_0 \left(\frac{dP}{dV}\right)_T$$ ORIGINAL VOLUME (RATE PRESSURE TO VOLUME) CONSTANT TEMP.

[TANGENT BULK MODULUS & POINT BULK MODULUS]

E = BULK MODULUS = 1/(COMPRESSIBILITY, β) ~TEMPERATURE CHANGE IS MINOR

BULK MODULUS of WATER, 1000 PSI

PRESSURE, PSI	32°F	68°F	120°F	200°F	300°F
15	292	320	332	308	
1500	300	330	340	319	218
4500	317	348	362	338	271
15,000	380	410	420	405	350

↳ = 320 000 + 6P   P (PRESSURE IN GAGE, PSI)

SPEED OF SOUND

REMEMBER 4th of JULY LIGHT & SOUNDS OF EVENTS

a = SPEED OF SOUND
ACOUSTICAL VELOCITY
SONIC VELOCITY

$$a = \sqrt{\frac{E}{\rho}} = \sqrt{\frac{1}{\beta\rho}} = \sqrt{\frac{E g_c}{\rho}} = \sqrt{\frac{g_c}{\beta\rho}}$$

E = BULK MODULUS OF SOLIDS

β = COMPRESSIBILITY

k = CONSTANT IDEAL GAS
R = CONSTANT IDEAL GAS

$$a = \sqrt{\frac{E}{\rho}} = \sqrt{\frac{kP}{\rho}} = \sqrt{kRT} = \sqrt{\frac{kR^*T}{MW}}$$

$$= \sqrt{\frac{Eg_c}{\rho}} = \sqrt{\frac{kg_cP}{\rho}}$$

$$= \sqrt{kg_cRT} = \sqrt{\frac{kg_c R^*T}{MW}}$$

$$\frac{a_1}{a_2} = \sqrt{\frac{T_1}{T_2}}$$ NEW SPEED @ DIFFERENT TEMPERATURE

M = MACH NUMBER = SPEED OF OBJECT IN A MED / SPEED OF SOUND IN MEDIUM
$= V/a$

SUB SONIC $M < 1$
SUPER SONIC $5 > M > 1$
HYPERSONIC $M > 5$
TRANSONIC $1.2 > M > 0.8$
SONIC BOOM WHEN (SHOCK WAVE) SUBSONIC TO SUPERSONIC

14 Fluid Properties

PRACTICE PROBLEMS

(Use $g = 32.2\ \text{ft/sec}^2$ or $9.81\ \text{m/s}^2$ unless told to do otherwise in the problem.)

Pressure

1. What is the absolute pressure if a gauge reads 8.7 psi (60 kPa) vacuum?

(A) 4 psi (27 kPa)
(B) 6 psi (41 kPa)
(C) 8 psi (55 kPa)
(D) 10 psi (68 kPa)

Viscosity

2. Calculate the kinematic viscosity of air at 80°F (27°C) and 70 psia (480 kPa).

(A) $3.54 \times 10^{-5}\ \text{ft}^2/\text{sec}$ ($3.30 \times 10^{-6}\ \text{m}^2/\text{s}$)
(B) $4.25 \times 10^{-5}\ \text{ft}^2/\text{sec}$ ($3.96 \times 10^{-6}\ \text{m}^2/\text{s}$)
(C) $4.96 \times 10^{-5}\ \text{ft}^2/\text{sec}$ ($4.62 \times 10^{-6}\ \text{m}^2/\text{s}$)
(D) $6.37 \times 10^{-5}\ \text{ft}^2/\text{sec}$ ($5.94 \times 10^{-6}\ \text{m}^2/\text{s}$)

Solutions

3. Volumes of an 8% solution, a 10% solution, and a 20% solution of nitric acid are to be mixed in order to get 100 mL of a 12% solution. If the 8% solution contributes half of the total volume of nitric acid contributed by the 10% and 20% solutions, what volume of 10% acid solution is required?

(A) 20 mL
(B) 30 mL
(C) 50 mL
(D) 80 mL

SOLUTIONS

1. *Customary U.S. Solution*

$$p_{\text{gage}} = -8.7\ \text{lbf/in}^2$$
$$p_{\text{atmospheric}} = 14.7\ \text{lbf/in}^2$$

The relationship between absolute, gage, and atmospheric pressure is given by

$$\begin{aligned} p_{\text{absolute}} &= p_{\text{gage}} + p_{\text{atmospheric}} \\ &= -8.7\ \frac{\text{lbf}}{\text{in}^2} + 14.7\ \frac{\text{lbf}}{\text{in}^2} \\ &= \boxed{6\ \text{lbf/in}^2\ \ (6\ \text{psi})} \end{aligned}$$

The answer is (B).

SI Solution

$$p_{\text{gage}} = -60\ \text{kPa}$$
$$p_{\text{atmospheric}} = 101.3\ \text{kPa}$$

The relationship between absolute, gage, and atmospheric pressure is given by

$$\begin{aligned} p_{\text{absolute}} &= p_{\text{gage}} + p_{\text{atmospheric}} \\ &= -60\ \text{kPa} + 101.3\ \text{kPa} \\ &= \boxed{41.3\ \text{kPa}} \end{aligned}$$

The answer is (B).

2. *Customary U.S. Solution*

For air at 14.7 psia and 80°F, the absolute viscosity independent of pressure is $\mu = 3.85 \times 10^{-7}\ \text{lbf-sec/ft}^2$.

Determine the density of air at 70 psia and 80°F. (Assume an ideal gas.)

$$\rho = \frac{p}{RT}$$

For air, $R = 53.3\ \text{lbf-ft/lbm-°R}$.

Substituting gives

$$\rho = \frac{\left(70\ \frac{\text{lbf}}{\text{in}^2}\right)\left(144\ \frac{\text{in}^2}{\text{ft}^2}\right)}{\left(53.3\ \frac{\text{lbf-ft}}{\text{lbm-°R}}\right)(80°\text{F} + 460)} = 0.350\ \text{lbm/ft}^3$$

The kinematic viscosity, ν, is related to the absolute viscosity by

$$\nu = \frac{\mu g_c}{\rho} = \frac{\left(3.85 \times 10^{-7}\ \frac{\text{lbf-sec}}{\text{ft}^2}\right)\left(32.2\ \frac{\text{lbm-ft}}{\text{lbf-sec}^2}\right)}{0.350\ \frac{\text{lbm}}{\text{ft}^3}} = \boxed{3.54 \times 10^{-5}\ \text{ft}^2/\text{sec}}$$

The answer is (A).

SI Solution

For air at 480 kPa and 27°C, the absolute viscosity independent of pressure is $\mu = 1.84 \times 10^{-5}$ Pa·s.

Determine the density of air at 480 kPa and 27°C. (Assume an ideal gas.)

$$\rho = \frac{p}{RT}$$

For air, $R = 287$ J/kg·K.

Substituting gives

$$\rho = \frac{(480\ \text{kPa})\left(1000\ \frac{\text{Pa}}{\text{kPa}}\right)}{\left(287\ \frac{\text{J}}{\text{kg·K}}\right)(27°\text{C} + 273)} = 5.575\ \text{kg/m}^3$$

The kinematic viscosity, ν, is related to the absolute viscosity by

$$\nu = \frac{\mu}{\rho} = \frac{1.84 \times 10^{-5}\ \text{Pa·s}}{5.575\ \frac{\text{kg}}{\text{m}^3}} = \boxed{3.30 \times 10^{-6}\ \text{m}^2/\text{s}}$$

The answer is (A).

3. Let

x = volume of 8% solution

y = volume of 10% solution

z = volume of 20% solution

The three conditions that must be satisfied are

$$x + y + z = 100\ \text{mL}$$
$$0.08x + 0.10y + 0.20z = (0.12)(100\ \text{mL}) = 12\ \text{mL}$$
$$0.08x = \left(\tfrac{1}{2}\right)(0.10y + 0.20z)$$

Simplifying these equations,

$$\begin{aligned} x + y + z &= 100 \\ 4x + 5y + 10z &= 600 \\ 8x - 5y - 10z &= 0 \end{aligned}$$

Adding the second and third equations gives

$$12x = 600$$
$$x = \boxed{50\ \text{mL}}$$

Work with the first two equations to get

$$y + z = 100 - 50 = 50$$
$$5y + 10z = 600 - (4)(50) = 400$$

Multiplying the top equation by -5 and adding to the bottom equation,

$$5z = 150$$
$$z = 30\ \text{mL}$$

From the first equation,

$$y = 20\ \text{mL}$$

The answer is (A).

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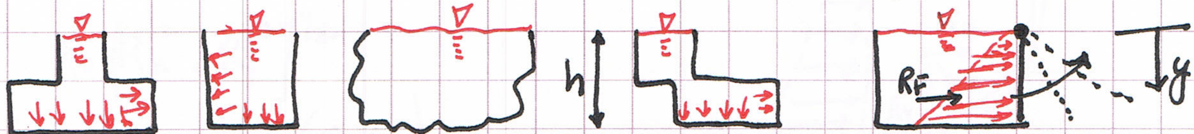
DETAILS — CIVIL . STRUCTURAL . ELECTRICAL . MECHANICAL . PLUMBING . ENERGY . LEED . GREEN — ENGINEERING & CONSULTING

PRESSURES ON HORIZONTAL & VERTICAL PLATES



HORIZONTAL FORCES: VARY FROM TOP LINEARLY INCREASING AS DISTANCE y INCREASES. TRIANGULAR SHAPE WITH CENTER OF FORCE BEING THE CENTER OF GEOMETRIC SHAPE of FORCE DISTRIBUTION

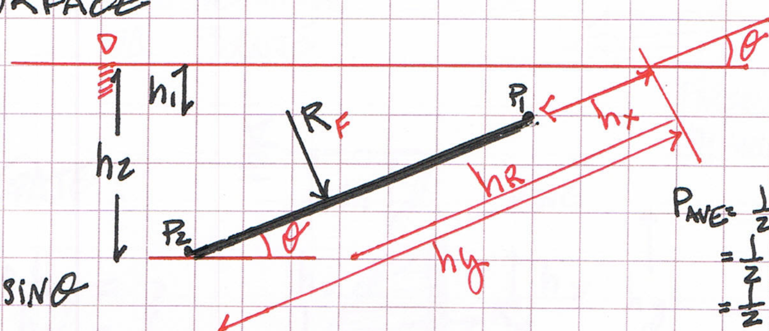
VERTICAL FORCE: ALWAYS SAME @ $p = \gamma h$
$F = pA$ BASE AREA
ONLY h is PARAMETER REGARDLESS of SHAPE

INCLINED SURFACE

$R_F = P_{AVE} A$

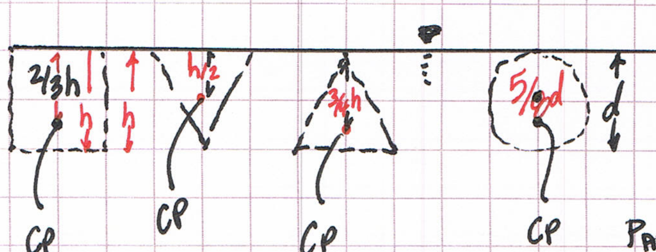
$P_{AVE} = \frac{1}{2}\gamma(h_1 + h_2)$

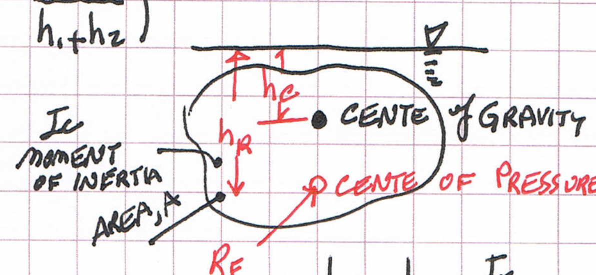
$= \frac{1}{2}\gamma(h_x + h_y)\sin\theta$



$P_{AVE} = \frac{1}{2}(P_1 + P_2)$
$= \frac{1}{2}\gamma(h_1 + h_2)$
$= \frac{1}{2}\gamma(h_x + h_y)\sin\theta$

$$h_R = \frac{2}{3}\left(h_x + h_y - \frac{h_x h_y}{h_x + h_y}\right) = \frac{2/3}{\sin\theta}\left(h_1 + h_2 - \frac{h_1 h_2}{h_1 + h_2}\right)$$





$h_R = h_c + \frac{I_c}{A h_c}$

$P_{AVE} = \gamma h_c \sin\theta$
$R_F = P_{AVE} A$

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REVISIONS

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

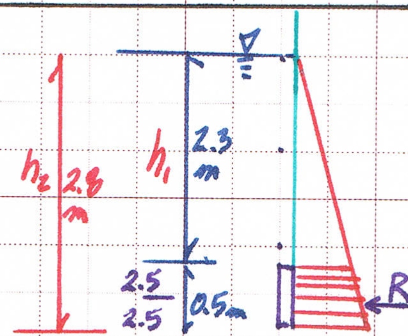
DETAILS | ENGINEERING & CONSULTING

GATE HINGED @ TOP TO PREVENT BACKFLOW OF TIDAL WATER INTO a 0.5m CIRCULAR STORM WATER. AT HIGH TIDE GATE (TOP) IS 2.3m BELOW WATER. WHAT FORCE IS REQUIRED TO OPEN GATE @ HIGH TIDE?

R = FORCE ON GATE IS CALCULATED @ CENTER OF GATE $= \frac{h_1+h_2}{2} = \frac{2.3+2.8}{2}$

$$R = A\Big|_{\substack{\text{GATE}\\ \text{AREA}}} \overbrace{\rho g}^{\gamma} \left(\frac{h_1+h_2}{2}\right) = \underbrace{\frac{\pi(0.5)^2}{4}}_{0.2m^2} \gamma \underbrace{\left(\frac{2.3+2.8}{2}\right)}_{2.55}$$

$$= 0.2m^2 \left(1000\frac{kg}{m^3} \cdot 9.81\frac{m}{s^2}\right) 2.55 = \underline{5003\,N}$$

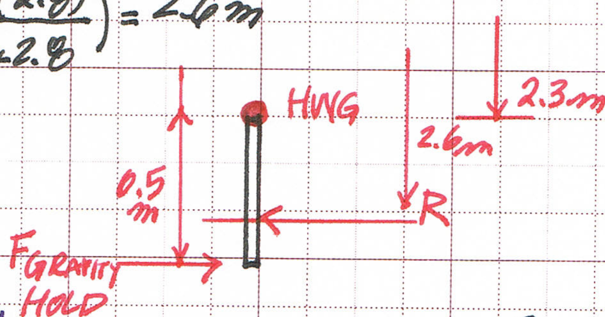


FORCE IS APPLIED @ 2/3 OF $\frac{2}{3}\left(h_1+h_2 - \frac{h_1 h_2}{h_1+h_2}\right) = d_R$

$$d_R = \frac{2}{3}\left(2.3+2.8 - \frac{2.3(2.8)}{2.3+2.8}\right) = 2.6m$$

$$\Sigma M_{HING} = \phi$$

$$F_G(0.5) = R(2.6-2.3)$$
$$= 5003(0.3)$$



$F_G = 3.0KN = 3000\,N$

$\underline{3000\,N}$

Hydraulics

Example 2

Fig. 6-3 shows two vertical submerged plane areas. Determine the hydrostatic force on each area and the point of application of each equivalent concentrated force.

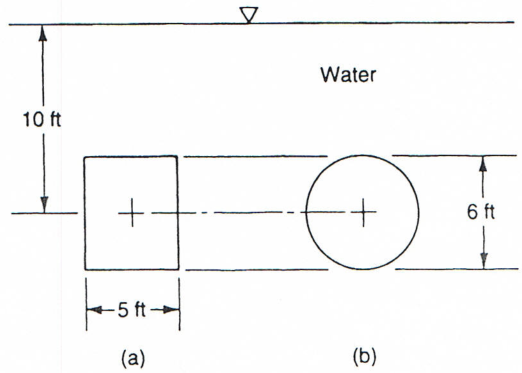


Fig. 6-3

Solution

For the rectangle of area $A = (6)(5) = 30\ \text{ft}^2$ in Fig. 6-3(a),

$F = \gamma h_C A = (62.4)(10)(30) = 18{,}700\ \text{lb}$

For the circle of area $A = \pi(6)^2/4 = 28.3\ \text{ft}^2$ in Fig. 6-3(b),

$F = \gamma h_C A = (62.4)(10)(28.3) = 17{,}700\ \text{lb}$

The moments of inertia of these two shapes about their respective centroids are

$$I = \frac{bh^3}{12} = \frac{(5)(6)^3}{12} = 90.0\ \text{ft}^4 \quad \text{and} \quad I = \frac{\pi}{4}R^4 = \frac{\pi}{4}(3)^4 = 63.6\ \text{ft}^4$$

Thus the distances down from the centroids to the actual point of application of these two forces are $I/(h_C A) = (90)/[(10)(30)] = 0.300$ ft and $I/(h_C A) = (63.6)/[(10)(28.3)] = 0.225$ ft, respectively.

CONSERVATION LAWS

Continuity

The principle of conservation of mass, often called simply **continuity,** can be written for a control volume of fixed volume, V, enclosed by a surface, S, as

$$\frac{\partial}{\partial t}\int_V \rho dV + \int_S \rho \mathbf{V} \cdot \mathbf{n} dS = 0 \tag{6}$$

The two terms express, in turn, the accumulation of mass within the volume and the net outflow of fluid across the boundary, S. The dot product of the velocity vector $\mathbf{V}$ and the unit outer normal $\mathbf{n}$ gives the component of the velocity normal to dS. If the flow is steady, the first term is zero. Applied to a single streamtube in steady incompressible flow, the principle is often written as

$$Q = \int_A V dA = \text{Constant} \tag{7}$$

or

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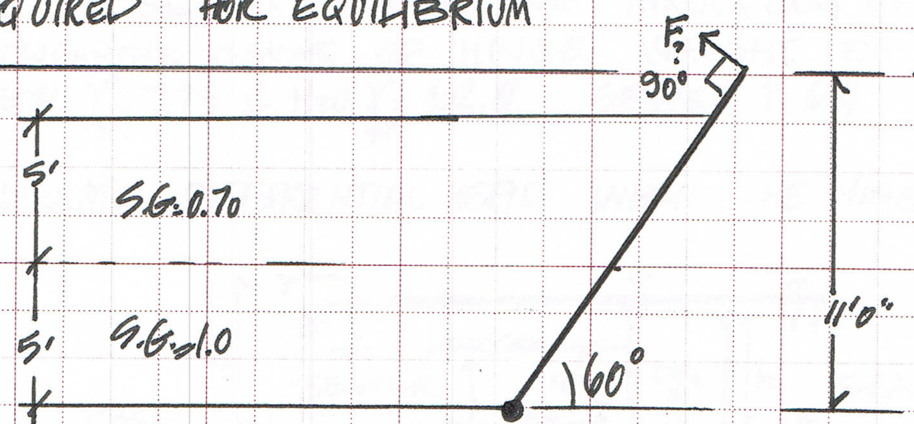
DETAILS | ENGINEERING & CONSULTING

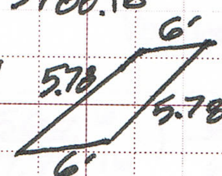
STEEL TANK IS 8 Ft WIDE. TWO FLUIDS ARE H_2O & OIL (S.G.=0.70). A 6' WIDE GATE IS HINGED AT BOTTOM. WHAT FORCE F IS REQUIRED FOR EQUILIBRIUM



- FORCE DUE TO OIL $F_o = \gamma_o \bar{h}_o A_o = 0.70(62.4)\frac{5}{2}\left(\frac{5}{\sin 60^\circ} * 6\right)$
  $= 3780\ lb$

  A_o 5' → 5'/SIN 60° * 6' WIDE

- $e_o = I_{cg}/A_o\bar{y}_o = \frac{6(5.78)^3/12}{(5.78)(6)(5.78/2)} = 0.963'$



$I = bh^3/12$
$\bar{y}_o = h/2$
$A = bh$

- FORCE DUE TO H_2O. (a) OIL EQUIV. HT (b) ADD TO H_2O

  $\gamma_o h_o = \gamma_w h_w \rightarrow h_w = \gamma_o h_o/\gamma_w = (0.70)5' = 3.5'$ H_2O EQUIV.

  $F_W = \gamma_w \bar{h}_w A_w = 62.4\left(3.5 + \frac{5}{2}\right)(5.78)(6) = 12980\ lb$

$e_w = I_{cg}/A_w\bar{y}_w = \frac{6(5.78)^3/12}{(5.78)(6)\left(\frac{5.78}{2} + \frac{3.5}{\sin 60^\circ}\right)} = 0.402$

- MOMENT ABOUT THE HINGE

$$F(11'/\sin 60^\circ) = F_W\left(\frac{5.78}{2} - e_2\right) + F_o\left(5.78 + 5.78/2 - e_1\right)$$

F = 4840 lb F

15 Fluid Statics

PRACTICE PROBLEMS

(Use $g = 32.2$ ft/sec^2 or 9.81 m/s^2 unless told to do otherwise in the problem.)

Buoyancy

1. A blimp contains 10,000 lbm (4500 kg) of hydrogen (specific gas constant = 766.5 ft-lbf/lbm-°R (4124 J/kg·K)) at 56°F (13°C) and 30.2 in Hg (770 mm Hg). What is its lift if the hydrogen and air are in thermal and pressure equilibrium?

(A) 7.6×10^3 lbf (3.4×10^4 N)
(B) 1.2×10^4 lbf (5.3×10^4 N)
(C) 1.3×10^5 lbf (5.9×10^5 N)
(D) 1.7×10^5 lbf (7.7×10^5 N)

2. A hollow 6 ft (1.8 m) diameter sphere floats half-submerged in seawater. What mass of concrete is required as an external anchor to just submerge the sphere completely?

(A) 2700 lbm (1200 kg)
(B) 4200 lbm (1900 kg)
(C) 5500 lbm (2500 kg)
(D) 6300 lbm (2700 kg)

SOLUTIONS

1. *Customary U.S. Solution*

Assume the weight of the blimp structure is small (negligible) compared with the weight of the hydrogen.

The lift of the hydrogen-filled blimp (F_{lift}) is equal to the difference between the buoyant force (F_b) and the weight of the hydrogen contained in the blimp (W_H).

$$F_{\text{lift}} = F_b - W_H$$

The weight of the hydrogen is calculated from the mass of hydrogen by

$$\begin{aligned} W_H &= \frac{mg}{g_c} \\ &= \frac{(10{,}000 \text{ lbm})\left(32.2 \frac{\text{ft}}{\text{sec}^2}\right)}{32.2 \frac{\text{lbm-ft}}{\text{lbf-sec}^2}} \\ &= 10{,}000 \text{ lbf} \end{aligned}$$

The buoyant force is equal to the weight of the displaced air. The weight of the displaced air is calculated by knowing that the volume of the air displaced is equal to the volume of hydrogen enclosed in the blimp. Compute the volume of the hydrogen contained in the blimp by assuming the hydrogen behaves like an ideal gas.

$$V_H = \frac{mRT}{p}$$

For hydrogen, $R = 766.5$ ft-lbf/lbm-°R.

The temperature of the hydrogen is given as 56°F. Convert to absolute temperature (°R).

$$T = 56°\text{F} + 460 = 516°\text{R}$$

The pressure of the hydrogen is given as 30.2 in Hg. Convert the pressure to units of pounds per square foot.

$$\begin{aligned} p &= (30.2 \text{ in Hg})\left(\frac{1 \frac{\text{lbf}}{\text{in}^2}}{2.036 \text{ in Hg}}\right)\left(144 \frac{\text{in}^2}{\text{ft}^2}\right) \\ &= 2136 \text{ lbf/ft}^2 \end{aligned}$$

Compute the volume of hydrogen.

$$V_H = \frac{mRT}{p} = \frac{(10{,}000\ \text{lbm})\left(766.5\ \frac{\text{ft-lbf}}{\text{lbm-°R}}\right)(516\text{°R})}{2136\ \frac{\text{lbf}}{\text{ft}^2}} = 1.85 \times 10^6\ \text{ft}^3$$

Since the volume of the hydrogen contained in the blimp is equal to the air displaced, the air displaced can be computed from the ideal gas equation by assuming the air behaves like an ideal gas.

$$m = \frac{pV_H}{RT}$$

Since the air and hydrogen are assumed to be in thermal and pressure equilibrium, the temperature and pressure are equal to the value given for the hydrogen.

For air, $R = 53.35$ ft-lbf/lbm-°R.

Substituting gives

$$m_{air} = \frac{pV_H}{RT} = \frac{\left(2136\ \frac{\text{lbf}}{\text{ft}^2}\right)(1.85 \times 10^6\ \text{ft}^3)}{\left(53.35\ \frac{\text{ft-lbf}}{\text{lbm-°R}}\right)(516\text{°R})} = 1.435 \times 10^5\ \text{lbm}$$

Recall that the buoyant force is equal to the weight of the air.

$$F_b = W_{air} = \frac{mg}{g_c} = \frac{(1.435 \times 10^5\ \text{lbm})\left(32.2\ \frac{\text{ft}}{\text{sec}^2}\right)}{32.2\ \frac{\text{lbm-ft}}{\text{lbf-sec}^2}} = 1.435 \times 10^5\ \text{lbf}$$

Therefore, the lift can be calculated as

$$F_{lift} = F_b - W_H = 1.435 \times 10^5\ \text{lbf} - 10{,}000\ \text{lbf} = \boxed{1.335 \times 10^5\ \text{lbf}}$$

The answer is (C).

SI Solution

Assume the mass of the blimp structure is small (negligible) compared with the mass of the hydrogen.

The lift of the hydrogen-filled blimp (F_{lift}) is equal to the difference between the buoyant force (F_b) and the weight of the hydrogen contained in the blimp (W_H).

$$F_{lift} = F_b - W_H$$

The weight of the hydrogen is calculated from the mass of hydrogen by

$$W_H = mg = (4500\ \text{kg})\left(9.81\ \frac{\text{m}}{\text{s}^2}\right) = 44\,145\ \text{N}$$

The buoyant force is equal to the weight of the displaced air. The weight of the displaced air is calculated by knowing that the volume of the air displaced is equal to the volume of hydrogen enclosed in the blimp. Compute the volume of the hydrogen contained in the blimp by assuming the hydrogen behaves like an ideal gas.

$$V_H = \frac{mRT}{p}$$

For hydrogen, $R = 4124$ J/kg·K.

The temperature of the hydrogen is given as 13°C. Convert to absolute temperature (K).

$$T = 13\text{°C} + 273 = 286\text{K}$$

The pressure of the hydrogen is given as 770 mm Hg. Convert the pressure to units of pascals.

$$p = \frac{(770\ \text{mm Hg})\left(133.4\ \frac{\text{kPa}}{\text{m}}\right)}{1000\ \frac{\text{mm}}{\text{m}}} = 102.7\ \text{kPa}$$

The volume of hydrogen is

$$V_H = \frac{mRT}{p} = \frac{(4500\ \text{kg})\left(4124\ \frac{\text{J}}{\text{kg·K}}\right)(286\text{K})}{(102.7\ \text{kPa})\left(1000\ \frac{\text{Pa}}{\text{kPa}}\right)} = 5.168 \times 10^4\ \text{m}^3$$

Since the volume of the hydrogen contained in the blimp is equal to the air displaced, the air displaced can be computed from the ideal gas equation assuming the air behaves like an ideal gas.

$$m = \frac{pV_H}{RT}$$

Since the air and hydrogen are assumed to be in thermal and pressure equilibrium, the temperature and pressure are equal to the value given for the hydrogen.

For air, $R = 287$ J/kg·K.

Substituting gives

$$m_{\text{air}} = \frac{pV_{\text{H}}}{RT}$$
$$= \frac{(102.7\ \text{kPa})\left(1000\ \frac{\text{Pa}}{\text{kPa}}\right)(5.168\times 10^4\ \text{m}^3)}{\left(287\ \frac{\text{J}}{\text{kg·K}}\right)(286\text{K})}$$
$$= 6.466\times 10^4\ \text{kg}$$

The buoyant force is equal to the weight of the air, so

$$F_b = W_{\text{air}} = mg$$
$$= (6.466\times 10^4\ \text{kg})\left(9.81\ \frac{\text{m}}{\text{s}^2}\right)$$
$$= 6.34\times 10^5\ \text{N}$$

Therefore, the lift can be calculated as

$$F_{\text{lift}} = F_b - w_{\text{H}}$$
$$= 6.34\times 10^5\ \text{N} - 44\,145\ \text{N}$$
$$= \boxed{5.90\times 10^5\ \text{N}}$$

The answer is (C).

2. *Customary U.S. Solution*

The weight of the sphere is equal to the weight of the displaced volume of water when floating.

The buoyant force is given by

$$F_b = \frac{\rho g V_{\text{displaced}}}{g_c}$$

Since the sphere is half submerged,

$$W_{\text{sphere}} = \left(\tfrac{1}{2}\right)\left(\frac{\rho g V_{\text{sphere}}}{g_c}\right)$$

For seawater, $\rho = 64.0$ lbm/ft^3.

The volume of the sphere is given by

$$V_{\text{sphere}} = \left(\frac{\pi}{6}\right)d^3$$
$$= \left(\frac{\pi}{6}\right)(6\ \text{ft})^3$$
$$= 113.1\ \text{ft}^3$$

The weight of the sphere is

$$W_{\text{sphere}} = \left(\tfrac{1}{2}\right)\left(\frac{\rho g V_{\text{sphere}}}{g_c}\right)$$
$$= \left(\tfrac{1}{2}\right)\left(\frac{\left(64.0\ \frac{\text{lbm}}{\text{ft}^3}\right)\left(32.2\ \frac{\text{ft}}{\text{sec}^2}\right)\times(113.1\ \text{ft}^3)}{32.2\ \frac{\text{lbm-ft}}{\text{lbf-sec}^2}}\right)$$
$$= 3619\ \text{lbf}$$

The buoyant force equation for a fully submerged sphere and anchor can be solved for the concrete volume.

$$W_{\text{sphere}} + W_{\text{concrete}} = (V_{\text{sphere}} + V_{\text{concrete}})\rho_{\text{water}}$$
$$W_{\text{sphere}} + \rho_{\text{concrete}}V_{\text{concrete}}\left(\frac{g}{g_c}\right) = (V_{\text{sphere}} + V_{\text{concrete}})\rho_{\text{water}} \times \left(\frac{g}{g_c}\right)$$
$$3619\ \text{lbf} + \left(150\ \frac{\text{lbm}}{\text{ft}^3}\right)(V_{\text{concrete}})\left(\frac{32.2\ \frac{\text{ft}}{\text{sec}^2}}{32.2\ \frac{\text{ft-lbm}}{\text{lbf-sec}^2}}\right) = (113.1\ \text{ft}^3 + V_{\text{concrete}}) \times \left(64.0\ \frac{\text{lbm}}{\text{ft}^3}\right) \times \left(\frac{32.2\ \frac{\text{ft}}{\text{sec}^2}}{32.2\ \frac{\text{ft-lbm}}{\text{lbf-sec}^2}}\right)$$
$$V_{\text{concrete}} = 42.09\ \text{ft}^3$$
$$m_{\text{concrete}} = \rho_{\text{concrete}}V_{\text{concrete}}$$
$$= \left(150\ \frac{\text{lbm}}{\text{ft}^3}\right)(42.09\ \text{ft}^3)$$
$$= \boxed{6314\ \text{lbm}}$$

The answer is (D).

SI Solution

The weight of the sphere is equal to the weight of the displaced volume of water when floating.

The buoyant force is given by

$$F_b = \rho g V_{\text{displaced}}$$

Since the sphere is half submerged,

$$W_{\text{sphere}} = \tfrac{1}{2}\rho g V_{\text{sphere}}$$

For seawater, $\rho = 1024$ kg/m^3.

The volume of the sphere is given by

$$V_{\text{sphere}} = \left(\frac{\pi}{6}\right)d^3$$
$$= \left(\frac{\pi}{6}\right)(1.8\ \text{m})^3$$
$$= 3.054\ \text{m}^3$$

The weight of the sphere required is

$$W_{\text{sphere}} = \tfrac{1}{2}\rho g V_{\text{sphere}}$$
$$= \left(\tfrac{1}{2}\right)\left(1024\ \frac{\text{kg}}{\text{m}^3}\right)\left(9.81\ \frac{\text{m}}{\text{s}^2}\right)(3.054\ \text{m}^3)$$
$$= 15\,339\ \text{N}$$

The buoyant force equation for a fully submerged sphere and anchor can be solved for the concrete volume.

$$W_{\text{sphere}} + W_{\text{concrete}} = (V_{\text{sphere}} + V_{\text{concrete}})\rho_{\text{water}}$$

$$W_{\text{sphere}} + \rho_{\text{concrete}} g V_{\text{concrete}} = g(V_{\text{sphere}} + V_{\text{concrete}})\rho_{\text{water}}$$

$$\begin{aligned} 15\,339\ \text{N} + \left(2400\ \frac{\text{kg}}{\text{m}^3}\right)\left(9.81\ \frac{\text{m}}{\text{s}^2}\right)(V_{\text{concrete}}) &= (3.054\ \text{m}^3 + V_{\text{concrete}}) \\ &\quad \times \left(1024\ \frac{\text{kg}}{\text{m}^3}\right)\left(9.81\ \frac{\text{m}}{\text{s}^2}\right) \end{aligned}$$

$$V_{\text{concrete}} = 1.136\ \text{m}^3$$

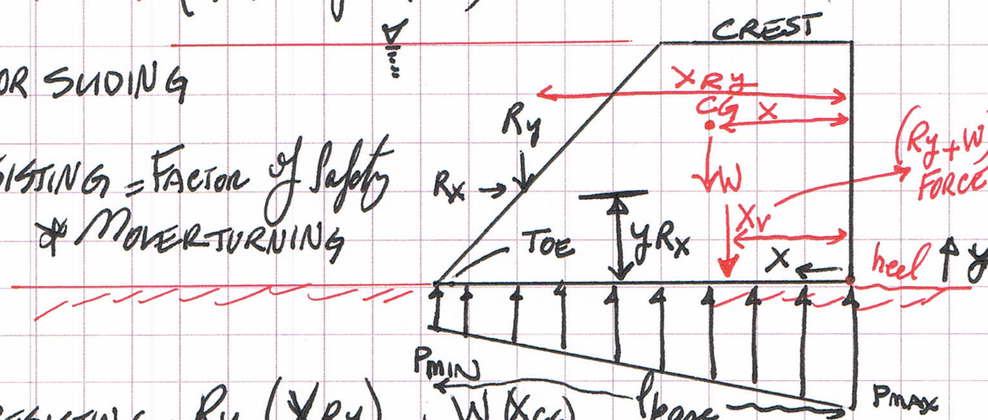
$$\begin{aligned} m_{\text{concrete}} &= \rho_{\text{concrete}} V_{\text{concrete}} \\ &= \left(2400\ \frac{\text{kg}}{\text{m}^3}\right)(1.136\ \text{m}^3) \\ &= \boxed{2726\ \text{kg}} \end{aligned}$$

The answer is (D).

DAM (GRAVITY DAM)

NO TIPPING OR SLIDING

$M_{\text{RESISTING}}$ = FACTOR of Safety * $M_{\text{OVERTURNING}}$



$$M_{\text{RESISTING}} = R_y (X_{Ry}) + W (X_{CG})$$

$$M_{\text{OVERTURNING}} = R_x \, y_{Rx}$$

WHAT ABOUT SLIDING $F_f = \mu_{\text{STATIC}} N = \mu_{\text{STATIC}} (W + R_y)$

$$\text{FACTOR of Safety}\Big|_{\text{SLIDING}} = F_f / R_x \quad \text{X DIRECTION}$$

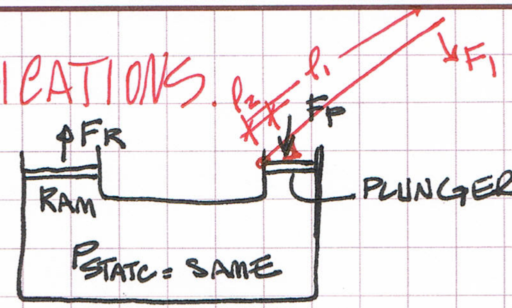
$$P_{MAX} = \left(\frac{R_y + W}{l_{BASE}}\right)\left(1 + \frac{6e}{l_{BASE}}\right); \quad P_{MIN} = \left(\frac{R_y + W}{l_{BASE}}\right)\left(1 - \frac{6e}{l_{BASE}}\right)$$

e = ECCENTRICITY $= \frac{l_{base}}{2} - X_{\text{VERTICAL FORCE}}$ (@ $R_y + W$)

$$X_V = (\text{MOMENT RESISTING}) / (R_y + W) = \frac{R_y X_{Ry} + X_{CG} W}{R_y + W}$$

$$e = \frac{l_{base}}{2} - (R_y X_{Ry} + X_{CG} W) / (R_y + W)$$

HYDROSTATIC APPLICATIONS



- HYDRAULIC RAM, JACK, PRESS

$F_P = PRESSURE_P * AREA_P$

$F_R = PRESSURE_P * AREA_{RAM}$

PRESSURE ARE SAME

$F_{PLUNGER} / AREA_{PLUNGER} = F_{RAM} / AREA_{RAM}$

F_{RAM} (RESULTING) $= F_{PLUNGER} \dfrac{AREA\ RAM}{AREA\ PLUNGER}$

$= F_{PLUNGER} \cdot \dfrac{(a*b)_{RAM}}{(a*b)_{PLUNGER}} = F_{PLUNGER} \dfrac{\pi d^2_{RAM}/4}{\pi d^2_{PLUNGER}}$

$= F_{PLUNGER} \cdot \dfrac{d^2_{RAM}}{d^2_{PLUNGER}}$

F (ARM) MOMENT.

$\Sigma M_o = \phi = (F_P)(l_2) - (F_1 l_1)$

$F_1 = F_P (l_2/l_1) \rightarrow F_P = \dfrac{F_1 l_1}{l_2}$

$F_{RAM} = \dfrac{F_1 l_1}{l_2} \dfrac{d^2_{RAM}}{d^2_{PLUNGER}} \eta$

(η = lever efficiency)

$F_{RAM} = F_1 \dfrac{l_1}{l_2} \eta \dfrac{AREA\ RAM}{AREA\ PLUNGER}$

- THIN WALLED TANK

σ hoop STRESS $= \dfrac{Pr}{t} = \dfrac{Pd}{2t}$
circumferential

σ_l LONGITUDINAL $= \dfrac{Pr}{2t} = \dfrac{Pd}{4t}$

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REVISIONS

DATE: SHEET:
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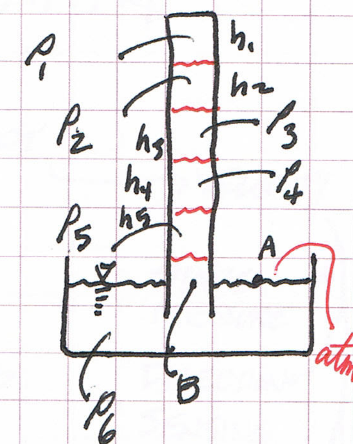
RE:

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

MULTILEVEL BAROMETER



$$P_a - P_v = g \sum \rho_i h_i = \frac{g}{g_c} \sum \rho_i h_i = \sum \gamma_i h_i$$

$$= g \left[\rho_1 h_1 + \rho_2 h_2 + \rho_3 h_3 + \rho_4 h_4 + \rho_5 h_5 \right.$$

$$P_E - P_{atm} = -\sum \rho_i g h_i$$

P_v = for air Can Be ignored if $((\rho_1 \gg \rho_{air})?)$
$\rho_1 \gg P_v$

FLUID PRESSURE MEASURING DEVICES

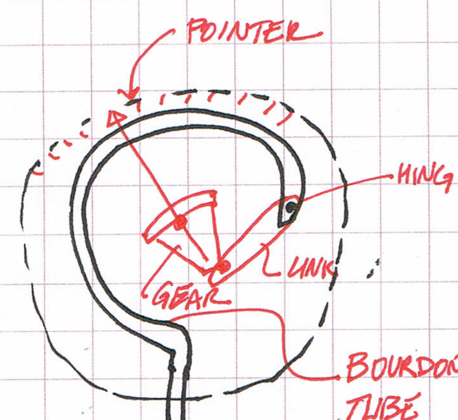
- BOURDON
- STATIC PRESSURE TUBE
- MANOMETER
- BAROMETER
- PIEZOELECTRIC EFFECT: STRAIN GAGE, DIAPHRAGM GAUGES, QUARTZ-CRYSTAL TRANSDUCERS

BOURDON PRESSURE GAUGE

(1→3000 ATM) & (0.1–1 ATM VACUUM)

IMAGINE A CURVED TUBE THAT UNDER PRESSURE TENDS TO STRAIGHTEN OUT. THE MOVEMENT OF TUBE MOVES A POINTER THAT INDICATES PRESSURE

DIAL WITH "ALTITUDE" Ft of H_2O
VACUUM in inches of Hg



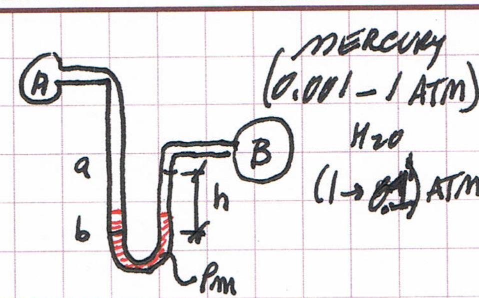
BAROMETER: MEASURE OF ABSOLUTE PRESSURE of ATMOSPHERE SIMILIAR TO MANOMETER USE ALCOHOL, MERCURY AS Fluid THE PRESSURE IS ONLY ATMOSPHERE (0→1ATM)

PIEZOELECTRIC: STRAIN GAUGES, DIAPHRAGM (0.001–700 ATM) GAUGES, (CRYSTAL) quartz TRANSDUCERS FOR FAST FLUCTUATION DESIGN.

ΔV, ΔI, ΔC (change in Volt, Amp, CAPACITANCE, RESISTANCE) ARE MEASURED AGAINST A CALIBRATED SYSTEM

MANOMETERS (U-tube)

SMALL PRESSURE DIFFERENCE WITH MOST ACCURACY < 10 Psi

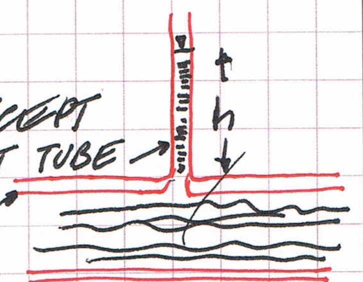


$$P_2 - P_1 = \rho_m g h$$

SOMETIMES A OR B ARE OPEN TO ATMOSPHERE, THEREFOR, PRESSURE IS "GAGE" PRESSURE

VACUUM SYSTEM CAN ALSO BE MEASURED

STATIC PRESSURE TUBE: USES MANOMETER CONCEPT

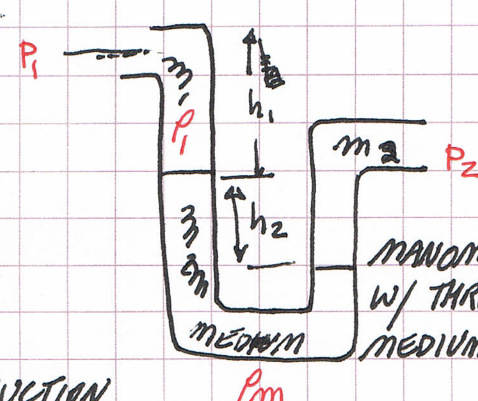


HEIGHT of WATER INDICATES THE STATIC PRESSURE

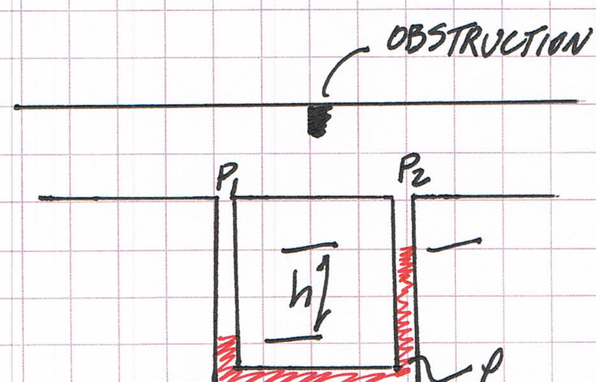
TAP INTO PIPES: 1/8" ϕ OR 1/4" ϕ, NONE of the PIPE TO BE EXPOSED TO FLOW INSIDE

5 TO 10 DIAMETERS FROM ANY TURBULENCE

$$P_2 - P_1 = g(\rho_m h + \rho_1 h_1 - \rho_2 h_2)$$
$$= g/g_c(\rho_m h + \rho_1 h_1 - \rho_2 h_2)$$
$$= \gamma_m h + \gamma_1 h_1 - \gamma_2 h_2$$



MANOMETER W/ THREE MEDIUMS

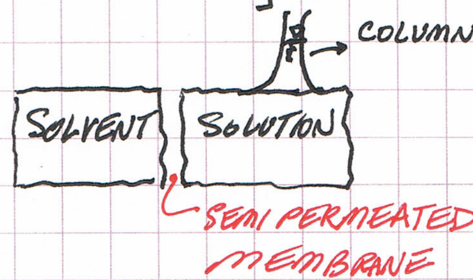


$$P_2 - P_1 = \rho g h$$

STATIC PRESSURE DIFFERENTIAL

OSMOTIC PRESSURE

OSMOSIS: DIFFUSION OF MOLECULES FROM ONE SOLVENT TO ANOTHER [SOLVET TO SOLUTION] IN ONE DIRECTION ONLY, THRU



OSMOTIC PRESSUE APPARATUS

: PROCESS CONTINUES TILL
(a) SUFFICIENT SOLVENT PASSED THRU TO MAKE ACTIVITY (OR SOLVENT PRESSURE) OF SOLUTION EQUALS SOLUTION PRESSURE

OSMOTIC PRESSURE APPARATUS: FLUID COLUMN = OSMOTIC PRESSURE

π : OSMOTIC PRESSURE, @ EQUILIBRIUM

- COLUMN PRESSURE INCREASES TILL EQUIVALENT IS REACHED
- TO DEVELOP AN ADJUSTMENT OR CONTROL of flow INTO SOLUTION: PRESSURE OF COLUMN IS CONTROLLED & ADJUSTED.

$$\pi = \rho g h \text{ or } \rho g h / g_c$$

- IN DILUTE SOLUTION: IDEAL GAS LAW $\pi = M R^* T$ M: MOLARITY