NAME CLEVELAND DATE 10 MAR 14

COURSE CE 3305 SHEET 1 OF 15

SCRIPT

ENERGY IS A MEASURE OF ABILITY TO DO WORK.

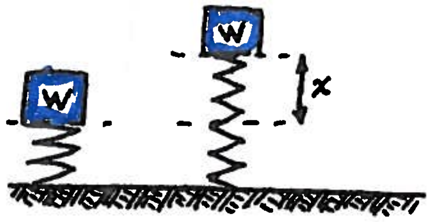
EXAMPLES:

- WATER STORED IN A DAM
- WIND ACROSS A PROPELLER
- GASOLINE BURNED IN A CYLINDER TO PUSH AGAINST A PISTON

BOARD

ENERGY CONCEPTS

ENERGY IS A PROPERTY THAT QUANTIFIES THE ABILITY TO DO WORK



SPRING LIFTS W, x UNITS — ENERGY STORED IN SPRING IS Wx

SCRIPT

KINDS OF ENERGY

MECHANICAL ENERGY — ENERGY ASSOCIATED WITH MOTION OR POSITION IN A FORCE FIELD.

THERMAL ENERGY — ENERGY ASSOCIATED WITH ΔT AND/OR PHASE CHANGE

CHEMICAL ENERGY CHEMICAL BONDS BREAKING RELEASE OR USE ENERGY

BOARD

UNITS OF ENERGY ARE:

JOULE = 1N·1m

1Ft·1lb = 1ft·lb

POWER IS ENERGY/TIME

$$\frac{1N\cdot m}{s}$$

$$\frac{1ft\cdot lb}{s}$$

SCRIPT

ELECTRICAL ENERGY

ENERGY ASSOCIATED WITH ELECTRICAL CHARGE IN AN ELECTRICAL FIELD

NUCLEAR ENERGY

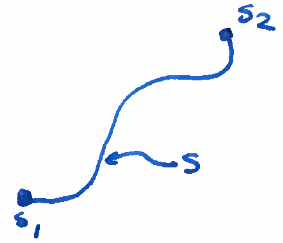
ENERGY ASSOCIATED WITH RADIOACTIVE DECAY

BOARD

WORK

$$W = F\cdot d$$

$$= \int_{1}^{2} F\,ds$$



Force (vector) applied through path s is work.

POWER

$$\frac{\text{WORK}}{\text{TIME}}$$

THIS IS VELOCITY

$$P = \frac{F\cdot \boxed{d}}{\boxed{t}} = F\cdot v$$

SCRIPT

TYPICAL "POWER"

LAPTOP COMPUTER, DISPLAY ON; FANS ON IS ABOUT 100W OR 100 J/s

WELL CONDITIONED SOLDIER CAN PRODUCE 300 J/s FOR AN HOUR OR TWO ~ 600W·hr OR 0.6 kW·hr WILL BURN OVER 2000 calories

BOARD

ENERGY IN FLUID SYSTEMS:

COMPRESSION = PRESSURE
ELEVATION = "POTENTIAL"
MOMENTUM = "KINETIC"

EXTRACTING ENERGY
- TURBINES
  - WATER (LIQUID)
  - AIR (GAS)

ADDING ENERGY
- PUMPS
  - LIQUIDS
- COMPRESSORS
  - GAS

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SCRIPT

THERMODYNAMICS IDEAS ARE FUNDAMENTAL TO ENERGY CONCEPT

- WORK
- HEAT TRANSFER

CONSIDER A BALLOON. PUT NEXT TO HEAT LAMP –

TEMP ↑

p ↑

PUSHES AGAINST RUBBER WALLS,

BOARD

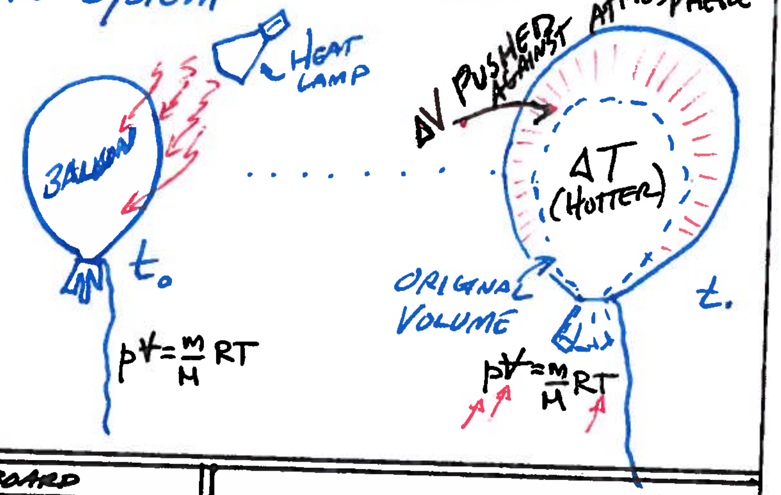
ENERGY BALANCE

HEAT TRANSFER INTO SYSTEM

$$\Delta E = \tilde{Q} - W$$

CHANGE IN ENERGY STORED IN SYSTEM

WORK DONE BY SYSTEM



SCRIPT

THE BALOON EXPANDS, PUSHES AGAINST ATMOSPHERE:

F·d ⇒ DID WORK

∴ ΔE ↑ BECAUSE Q ↑. SOME ΔE LOST BECAUSE BALLOON HAD TO PUSH AGAINST ATMOSPHERE (W)

BOARD

AS A RATE EXPRESSION THE 1st LAW OF THERMODYNAMICS IS

$$\frac{dE}{dt} = \underbrace{\frac{d\tilde{Q}}{dt} - \frac{dW}{dt}}$$

THESE ARE OFTEN WRITTEN AS

$$\frac{dE}{dt} = \dot{Q} - \dot{W}$$

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SCRIPT

NOW APPLY REYNOLD'S TRANSPORT THEOREM

e IS INTENSIVE PROPERTY $\frac{E}{m}$.

U IS INTERNAL ENERGY; IT IS COMPRISED OF "PRESSURE" + CHEMICAL; NUCLEAR; ELECTRICAL, ENERGY

"PRESSURE" IS STRONGLY TEMPERATURE DEPENDENT

BOARD

$$\left.\frac{dQ}{dt} - \frac{dW}{dt}\right|_{sys} = \frac{d}{dt}\int_{C.V.} \varphi e \, d\forall + \int_{C.S.} \varphi e \, \vec{V} \cdot d\vec{A}$$

e – ENERGY PER UNIT MASS

$$e = e_k + e_{pot.} + U$$

U = INTERNAL ENERGY (ENERGY A SUBSTANCE POSESSES BY STATE OF MOLECULAR ACTIVITY)

SCRIPT

IN "U".

FLOW WORK (AT A SECTION IS DIAGRAMED PG 258)

BOARD

$\frac{d\tilde{Q}}{dt} = \dot{Q}$ = HEAT TRANSFER INTO ~~SYSTEM~~ C.∀.

$\frac{dW}{dt} = \dot{W}$ = WORK DONE $\underline{\underline{\text{BY}}}$ C.∀.

FLOW WORK

$WORK = F \cdot d \quad \therefore dW = F dx$

THUS $\frac{dW}{dt} = F\frac{dx}{dt} = F.V$

(DIMENSIONALLY A POWER!)

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SCRIPT

p IS PRESSURE AT SECTION ①

V IS VELOCITY AT SECTION ①

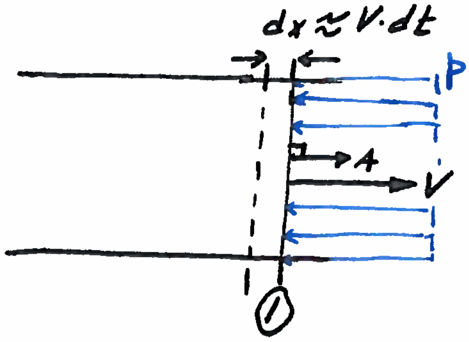
A IS OUTWARD POINT AERA VECTOR

dx IS SMALL REGION JUST AS GET TO ①

$dx \approx V\cdot dt$

RELATE PRESSURE FORCE TO MOMENTUM

BOARD



CONSIDER MOMENTUM AT ①

$$F_p = \int_{c.s.} \vec{V} \rho \vec{V}\cdot d\vec{A}$$

$$pA = \rho V^2 A$$

DISTANCE THE FORCE APPLIED IS

$$dx = Vdt$$

SCRIPT

NOW APPLY THIS FORCE THROUGH dx TO FIND WORK THE FLOW DOES AT SECTION ①

SO WHEN APPLY FORCE TO dx IN TERMS $dx = Vdt$

FIND THAT

$$\dot{W} = pQ = \rho V^2 Q$$

Q IS DISCHARGE

(HERE IS UNFORTUNATE CASE WHERE Q = DISCHARGE)
$\dot{Q}$ = HEAT FLOW

BOARD

$$\therefore \quad F_p\, dx = pAVdt = \rho V^2 A\cdot Vdt$$

THUS

$$\dot{W} = F_p \underset{\overset{\uparrow}{V}}{\frac{dx}{dt}} = pAV = \rho V^2 AV$$

SO

$$F\cdot V = p\underbrace{AV}_{Q} = \rho V^2 \underbrace{AV}_{Q} = \dot{W}$$

(DISCHARGE)

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SCRIPT

USUALLY FLOW WORK IS INCORPORATED INTO THE FLUX INTEGRAL

NOW USE THESE TERMS IN ENERGY EQUATION

BOARD

$$\int_{C.S.} \rho\left(\frac{p}{\rho}+e\right)\vec{V}\cdot d\vec{A}$$

NOW CONSIDER e FORMS

$$e_k = \frac{\text{KINETIC ENERGY}}{\text{MASS}} = \frac{\frac{mV^2}{2}}{m} = \frac{V^2}{2}$$

$$e_p = \frac{\text{GRAVITATIONAL ENERGY}}{\text{MASS}} = \frac{mgz}{m}$$

$$= gz$$

SCRIPT

NOTE THE FLOW WORK IS IN THE INTEGRAL

$\dot{W}_s$ IS "SHAFT" WORK

- ITS A SUPERFLY THING!

BOARD

$$\dot{Q}-\dot{W}_s = \frac{d}{dt}\int_{C.V.} \rho\left(\frac{V^2}{2}+gz+u\right)d\forall$$

$$+\int_{C.S.} \rho\left(\frac{p}{\rho}+\frac{V^2}{2}+gz+u\right)\vec{V}\cdot d\vec{A}$$

- FLOW WORK REPRESENTS THE ENERGY REQUIRED FOR THE FLUID TO FLOW AGAINST PRESSURE FORCES (BACK PRESSURE)
- SHAFT WORK REPRESENTS ENERGY THAT CAN BE REMOVED BY MECHANICAL DEVICES FROM THE FLOW FIELD AND PUT TO USE

SCRIPT

APPLICATION OF CONCEPT

DRAW C.∀., C.S.

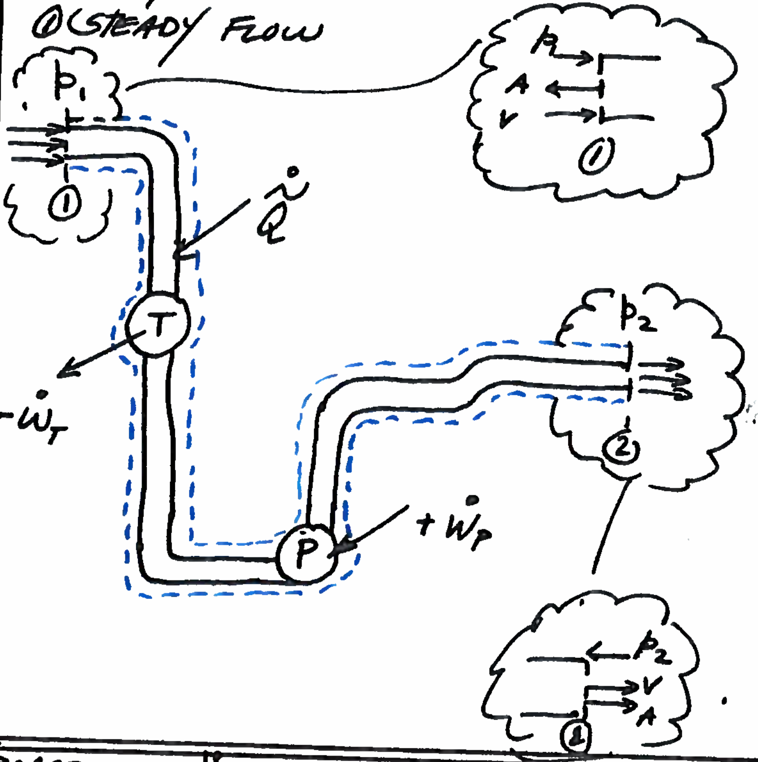
NOTE p, V, A AT INLETS/OUTLETS

WRITE ENERGY BALANCE

BOARD

ENERGY IN A PIPELINE

① STEADY FLOW



SCRIPT

OBSERVE THAT

$$\dot{W}_s = \dot{W}_P - \dot{W}_T$$

NOW EVALUATE THE FLUX INTEGRALS

BOARD

$$\dot{Q}-\dot{W}_s = \cancel{\frac{d}{dt}\int_{c.\forall.}\left(\frac{V^2}{2}+gz+u\right)\rho\, d\forall}$$

0 (steady flow)

$$+\int_{①}\left(\frac{p_1}{\rho}+gz_1+\frac{V_1^2}{2}+u_1\right)\rho\vec{V}\cdot d\vec{A}$$

$$+\int_{②}\left(\frac{p_2}{\rho}+gz_2+\frac{V_2^2}{2}+u_2\right)\rho\vec{V}\cdot d\vec{A}$$

SCRIPT

INTEGRAL AT SECTION ① IS

7
~~8~~
2

INTEGRAL AT SECTION ② IS :

BOARD

$$\int_{①} \frac{p_1}{\rho}\cdot\rho\vec{V}d\vec{A}+\int_{①}\rho g z_1\vec{V}\cdot d\vec{A}+\int_{①}\rho\frac{V_1^2}{2}\vec{V}\cdot d\vec{A}$$

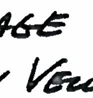
$$+\int_{①}\rho u_1\vec{V}\cdot d\vec{A}$$

$$\int_{②} \frac{p_2}{\rho}\rho\vec{V}\cdot d\vec{A}+\int_{②}\rho g z_2\vec{V}\cdot d\vec{A}+\int_{②}\rho\frac{V_2^2}{2}\vec{V}\cdot d\vec{A}$$

$$+\int_{②}\rho u_2\vec{V}\cdot d\vec{A}$$

SCRIPT

USE FLOW DIAGRAM TO EVALUATE SIGN V·dA

INTRODUCE KINETIC ENERGY CORRECTION COEFFICIENTS WHICH RELATE K.E. DISTRIBUTED ACROSS V(r) 

TO AN AVERAGE (MEAN SECTION VELOCITY)

BOARD

$$=-\frac{p_1}{\rho}\rho Q-gz_1\rho Q-\frac{\alpha_1V_1^2}{2}\rho Q-u_1\rho Q$$

$$+\frac{p_2}{\rho}\rho Q+gz_2\rho Q+\frac{\alpha_2V_2^2}{2}\rho Q+u_2\rho Q$$

α_1 & α_2 ARE KINETIC ENERGY CORRECTION FACTORS

$$\int\rho\frac{V_1^2}{2}\vec{V}\cdot d\vec{A} \qquad \bar{V}_1=\frac{\int V\cdot dA}{\int dA}$$

$$=\int\frac{\rho}{2}V_1^3dA_1=\frac{\rho}{2}\int V_1^3dA_1=\frac{\rho}{2}\alpha_1\int\bar{V}_1^3dA$$

$$\therefore\ \alpha_1=\int V_1^3dA\Big/\int\bar{V}_1^3dA$$

SCRIPT

TYP. VALUES α

$1 \leq \alpha \leq 2$

$\uparrow$ TURBULENT

$\uparrow$ LAMINAR

DIVIDE BY g
AND REARRANGE
EQUATION

BOARD

RESULT IS

$$\dot{Q} + \dot{W}_p - \dot{W}_T = -\frac{p_1}{\rho}\cancel{\rho} Q - g z_1 \rho Q - \frac{\alpha_1 V_1^2}{2}\rho Q - u_1 \rho Q$$

$$+ \frac{p_2}{\rho}\cancel{\rho} Q + g z_2 \rho Q + \frac{\alpha_2 V_2^2}{2}\rho Q + u_2 \rho Q$$

REARRANGE AND DIVIDE BY g

$$\underbrace{\frac{\dot{W}_p}{\rho Q g}}_{\text{ADDED HEAD (PUMP)}} + \frac{p_1}{\rho g} + \frac{g z_1}{g} + \frac{\alpha_1 V_1^2}{2g} = \frac{p_2}{\rho g} + \frac{g z_2}{g} + \frac{\alpha_2 V_2^2}{2g}$$

$$+ \underbrace{\frac{\dot{W}_T}{\rho Q g}}_{\text{REMOVED HEAD (TURBINE)}} + \underbrace{\frac{u_2 - u_1}{\rho Q g} - \frac{\dot{Q}}{\rho Q g}}_{\text{HEAD LOSS}}$$

SCRIPT

OBSERVE DIMENSIONS ARE LENGTH.

THEY ARE CALLED "HEAD"

THEY REPRESENT
ENERGY PER UNIT
WEIGHT OF FLUID

BOARD

USUALLY THIS LAST EXPRESSION IS WRITTEN (AND MEMORIZED) AS

$$\frac{p_1}{\gamma} + \frac{\alpha_1 V_1^2}{2g} + z_1 + h_p = \frac{p_2}{\gamma} + \frac{\alpha_2 V_2^2}{2g} + z_2 + h_T + h_L$$

NOTICE THE REMARKABLE SIMILARITY TO BERNOULLI'S EQUATION!

EXAMINE COMMON NAMES FOR EACH TERM

$\frac{p}{\gamma}$ → "PRESSURE HEAD"

SCRIPT

THE EXPRESSION IS VALID FOR STEADY, ONE-DIMENSIONAL (AXIAL), INCOMPRESSIBLE FLOW IN A PIPE

IN ABSENCE OF FRICTIONAL LOSSES AND HEAT TRANSFER

$h_L = 0$

(INVISCID FLOW)

BOARD

$\frac{\alpha V^2}{2g} \rightarrow$ "VELOCITY HEAD"

(α IS USUALLY UNITY IN MANY PRACTICAL FLOW)

$z \rightarrow$ "ELEVATION HEAD"

$\frac{p}{\gamma} + z \rightarrow$ "STATIC HEAD"

$\frac{p}{\gamma} + z + \frac{\alpha V^2}{2g} \rightarrow$ " TOTAL HEAD"

"TOTAL DYNAMIC HEAD"

SCRIPT

THIS IS A FUNDAMENTAL TOOL IN <u>HYDRAULICS</u>

BOARD

EXAMPLE

A PUMP DRAWS WATER FROM RESERVOIR A AND LIFTS IT TO A HIGHER RESERVOIR B.

THE HEAD LOSS FROM A TO THE PUMP IS 4 TIMES THE VELOCITY HEAD.

THE HEAD LOSS FROM THE PUMP TO B IS ~~SEVEN~~ 7 TIMES THE VELOCITY HEAD IN THE PIPE. FIND THE PRESSURE HEAD THE PUMP MUST DELIVER IF PRESSURE AT THE PUMP SUCTION INLET IS −6 M OF WATER

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SCRIPT

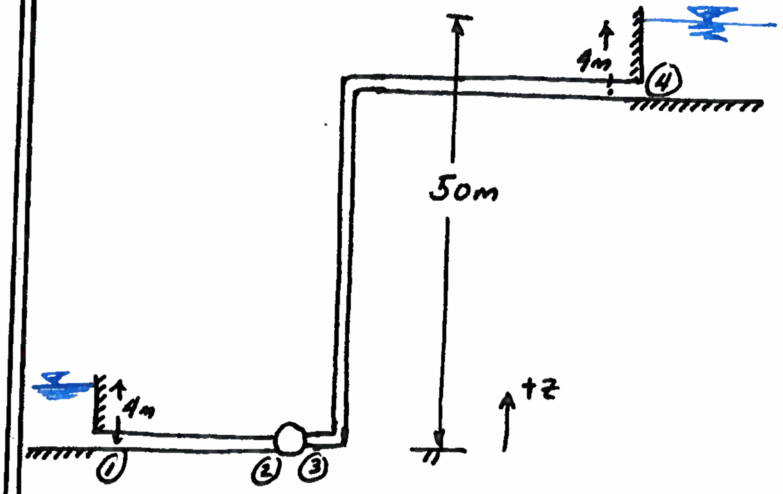
APPLY ENERGY EQUATION FROM ① → ②

THEN ③ → ④

USE CONTINUITY AS NEEDED.

BOARD

(SKETCH; WITH VARIOUS ELEVATIONS



SCRIPT

BOARD

ENERGY ① → ②

$$h_1 + \cancel{h_p} = h_2 + \cancel{h_T} + h_L$$

0 NO PUMP BETWEEN 1 & 2

0 NO TURBINE BETWEEN 1 & 2

EXPAND EXPRESSIONS FOR WHAT'S LEFT

$$h_1 = \frac{p_1}{\gamma} + \frac{V_1^2}{2g} + z_1 \quad ; \quad h_2 = \frac{p_2}{\gamma} + \frac{V_2^2}{2g} + z_2$$

$$h_L = \frac{4V^2}{2g}$$

CONTINUITY

$V = V_1 = V_2$ (CONSTANT DIAMETER PIPE)

$$\therefore \frac{p_1}{\gamma} + \cancel{\frac{V_1^2}{2g}} + \cancel{z_1} = \frac{p_2}{\gamma} + \cancel{\frac{V_2^2}{2g}} + \cancel{z_2} + \frac{4V^2}{2g}$$

SCRIPT

BOARD

$$\frac{p_1}{\gamma} = \frac{p_2}{\gamma} + \frac{4V^2}{2g} \qquad \frac{p_1}{\gamma} = 4m$$

$$\frac{p_2}{\gamma} = -6m$$

So

$$\left(\frac{p_1 - p_2}{\gamma}\right)\frac{2g}{4} = V^2$$

$$V = \sqrt{\frac{(10m)(2)(9.8m/s^2)}{4}} = 7m/s$$

ENERGY FROM ③ → ④

$$\frac{p_3}{\gamma} + \frac{V_3^2}{2g} + \underset{=0}{\cancel{z_3}} + \underset{0}{\cancel{h_p}} = \frac{p_4}{\gamma} + \frac{V_4^2}{2g} + z_4 + \underset{=0}{\cancel{h_t}} + h_L$$

No PUMPS 3→4 No TURB. 3→4

SCRIPT

BOARD

$V_3 = V_4$ CONSTANT DIAMETER PIPE

∴

$$\frac{p_3}{\gamma} = \frac{p_4}{\gamma} + z_4 + h_L \qquad h_L = \frac{7V^2}{2g}$$

$$\frac{p_3}{\gamma} = \frac{p_4}{\gamma} + z_4 + \frac{7V^2}{2g}$$

$$z_4 = 50m \qquad \frac{p_4}{\gamma} = 4m$$

$$h_L = \frac{7(7)^2}{2g} = 17.5m$$

$$\therefore \frac{p_3}{\gamma} = 4m + 50m + 17.5m = 71.5m$$

SCRIPT

BOARD

ENERGY ② → ③ (ACROSS PUMP)

$$\frac{p_2}{\gamma}+\frac{V_2^2}{2g}+z_2+h_p=\frac{p_3}{\gamma}+\frac{V_3^2}{2g}+z_3+\underbrace{h_t}_{=0 \text{ No TURB.}}+\overbrace{h_L}^{\sim 0}$$

ASSUME $V_2 \approx V_3$

ASSUME h_L IN MACHINE IS NEGLIGIBE (ITS NOT, BECOMES PART MACHINE EFFICIENCY)

$$\frac{p_2}{\gamma}+h_p=\frac{p_3}{\gamma}$$

$$h_p=\frac{p_3}{\gamma}-\frac{p_2}{\gamma}=71.5m-(-6m)$$

$$=77.5m$$

ADDED HEAD REQUIRED BY THE PUMP

SCRIPT

HGL & EGL (pg 273-277)

BOARD

HYDRAULIC & ENERGY GRADE LINES

$$\underbrace{\underbrace{\frac{p_1}{\gamma}+z_1}_{\text{STATIC HEAD}}+\frac{V_1^2}{2g}}_{\text{TOTAL HEAD}}$$

THE HYDRAULIC GRADE LINE (HGL) IS AN IMAGINARY LINE THAT CONNECTS THE STATIC HEAD IN THE SYSTEM

ITS HEIGHT REPRESENTS THE "STATIC" ENERGY OF THE SYSTEM AT SOME POINT.

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SCRIPT

BOARD

THE ENERGY GRADE LINE IS AN IMAGINARY LINE THAT CONNECTS TOTAL HEAD IN THE SYSTEM.

- ITS HEIGHT REPRESENTS TOTAL ENERGY OF THE SYSTEM AT SOME POINT.

HGL = HYDRAULIC GRADE LINE
EGL = ENERGY GRADE LINE

SCRIPT

DRAWING

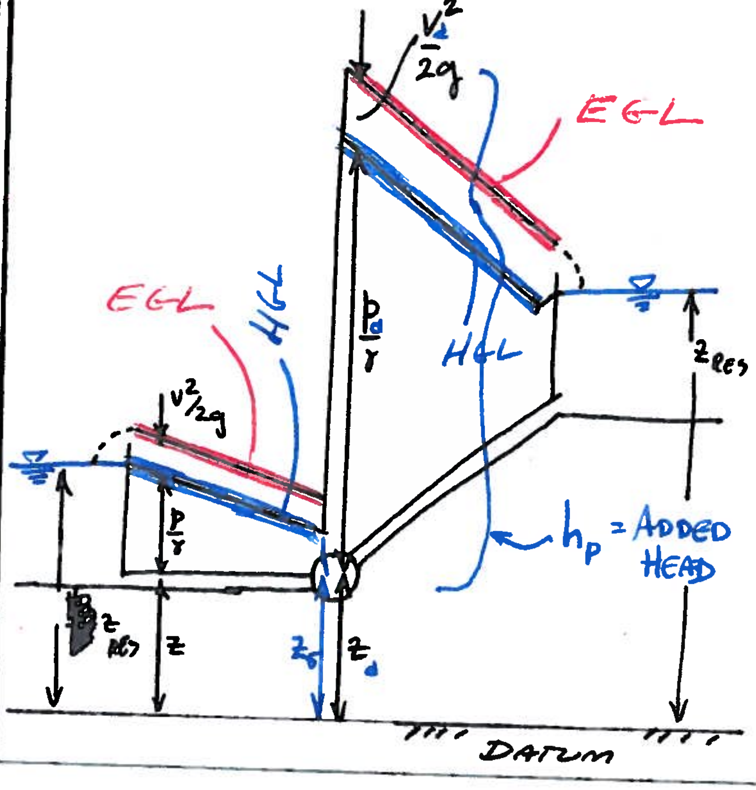
$HGL = \frac{p}{\gamma} + z$ (BLUE)

$EGL = HGL + \frac{V^2}{2g}$ (RED)

ADDED HEAD IS

$$\frac{p_d}{\gamma} + \frac{V_d^2}{2g} - \frac{p_s}{\gamma} - \frac{V_s^2}{2g} = h_p$$

BOARD



SCRIPT

CAVITATION DESCRIBED PG 191

BOARD

DRAWING HGL/EGL

① HEAD LOSS IN SYSTEM IMPLIES HGL SLOPES DOWNWARD IN DIRECTION OF FLOW.

② A PUMP ADDS TOTAL HEAD TO A SYSTEM SO THE EGL JUMPS

③ $\frac{p}{\gamma}=0$ HGL = WATER LINE

④ $\frac{p}{\gamma}<0$ POSSIBLE CAVITATION (pg 191)

SCRIPT

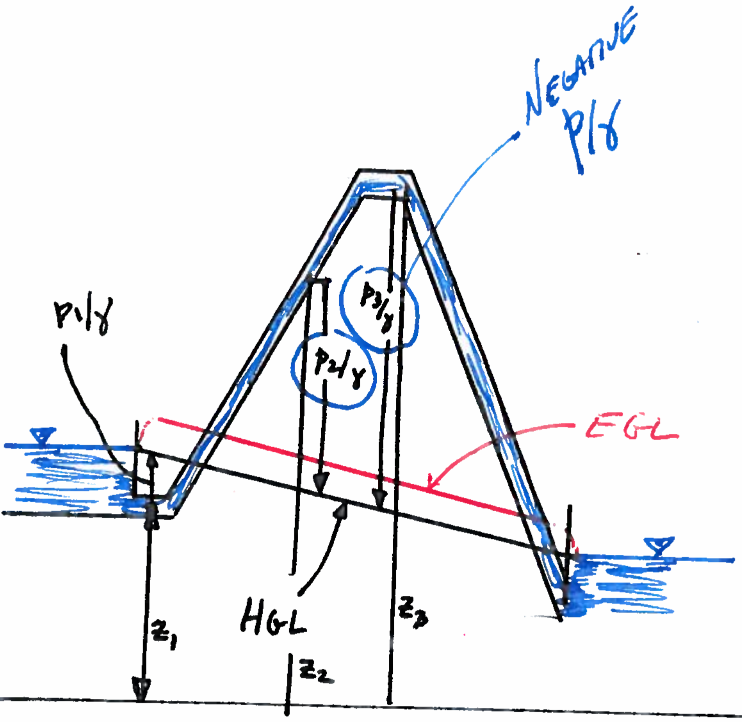
IMPORTANCE OF NEGATIVE PRESSURE DEPENDS ON WORKING FLUID

FOR WATER

$\frac{p}{\gamma} < -10m$

THEN ARE CLOSE TO VAPOR PRESSURE AND WILL FORM VAPOR BUBBLES, WHICH IS BAD — LIKE CROSSING THE BEAMS (GHOST BUSTERS)

BOARD



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SCRIPT

BOARD

GOOD EXERCISES

7.25
7.34
7.40
7.48
7.56
7.61
7.87
7.82

DO 4x4

7.25
7.34
7.40
7.48

7.56
7.61
7.82
7.87

TYPESET

GOOD EXAM QUESTIONS

7.29
7.78 + SUBSET EXERCISES

SCRIPT

BOARD