SCRIPT

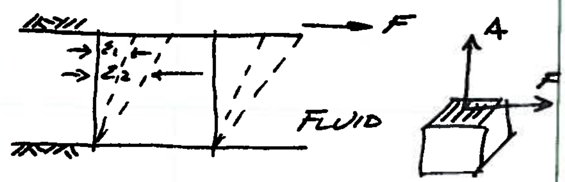
- ROLL SHEET
- QUIZ #1 10 MINUTES
- FLUID PROPERTIES DESCRIBE THE PHYSICAL CONDITION OF A FLUID

BOARD

REVIEW:

WHAT IS A FLUID?

- CONTINUOUS DEFORMATION UNDER APPLIED STRESS



$$\varepsilon \propto \frac{F}{A} = \tau$$

$$\varepsilon \propto time \Rightarrow \varepsilon = g(\tau, t)$$

$$\frac{d\varepsilon}{dt} \neq 0$$

SCRIPT

- EXTENSIVE PROPERTIES RELATE TO A SYSTEM; A DEFINED QUANTITY OF MASS
- INTENSIVE PROPERTIES RELATE TO COMPONENTS OF A SYSTEM; A VOLUME IN SPACE
  REV
  - USE GALLON OF WATER AS EXAMPLE

pp 28-29

BOARD

EXTENSIVE AND INTENSIVE PROPERTIES

EXTENSIVE: SYSTEM; DEFINED QUANTITY OF MASS

INTENSIVE: SYSTEM COMPONENTS
PROPERITES RELATED TO A BOUNDARY IN SPACE

W - WEIGHT IS AN EXTENSIVE PROPERTY

γ - SPECIFIC WEIGHT; WEIGHT PER VOLUME IS AN INTENSIVE PROPERTY

SCRIPT

- TAKE A GALLON OF WATER; WEIGH THE GALLON, TARE THE VESSEL WEIGHT.

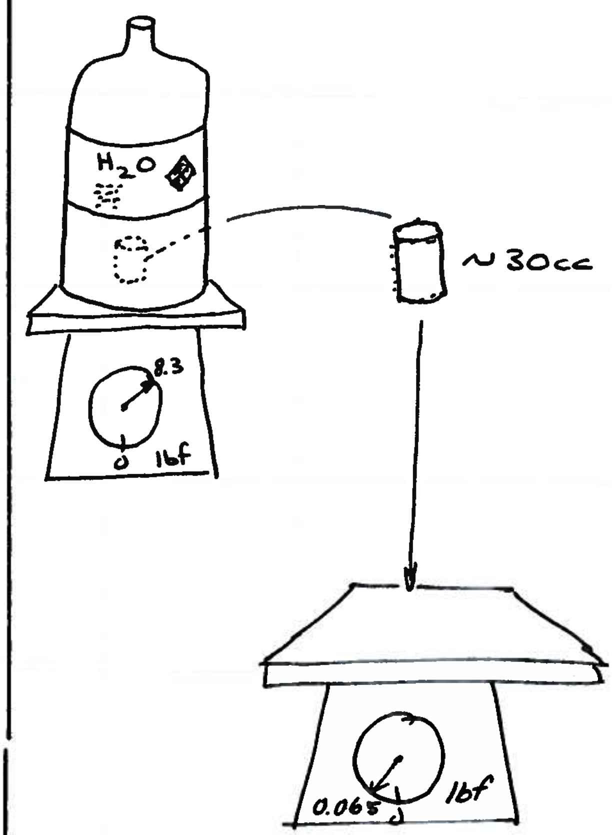
- TAKE ~30cc FROM THAT GALLON; WEIGH THE 30 cc.

$1 \text{ gal} \approx 8.3 \text{ lbf}$

$30\text{cc} \approx 0.06484 \text{ lbf}$
(USE 0.065)

EXTENSIVE – WHOLE MASS OF SYSTEM
(GALLON OR THE 30cc)

BOARD



SCRIPT

NOW COMPUTE THE SPECIFIC WEIGHT OF THE GALLON.

8.32 lbf/gal

NOW COMPUTE SP. WEIGHT OF THE 30cc.

WITH UNIT CONVERSIONS

8.32 lbf/gal

∴ SAME VALUE.

SP. WEIGHT IS INTENSIVE PROPERTY.

BOARD

THE GALLON WEIGHS 8.3 lbf

THE 30cc WEIGHS 0.065 lbf

$$\gamma_{gallon} = \frac{8.3 \text{ lbf}}{1 \text{ gal}} = 8.3 \text{ lbf/gal}$$

$$\gamma_{30cc} = \frac{0.065 \text{ lbf}}{\cancel{30cc}} \cdot \frac{\cancel{30cc}}{\cancel{1oz}} \cdot \frac{128\cancel{oz}}{\text{gal}}$$

$$= 8.32 \text{ lbf/gal}$$

THE ~~UNIT~~ SPECIFIC WEIGHT (INTENSIVE) IS 8.3 lbf/gal FOR THE WATER!

SCRIPT

• FLUID PROPERTIES INVOLVE SEVERAL PRIMARY DIMENSIONS

· m, L, t, T

(pg 30 – 32)

· START WITH MASS.

• DEFINE MASS DENSITY

• DEFINE SP. WEIGHT

• RELATE $\gamma = \rho g$

• DEFINE SP. GRAVITY

• NOTE Hg WEIGHS 13X EQUIVALENT VOLUME WATER

$\therefore \; S.G._{Hg} = 13.6$

BOARD

FLUID PROPERTIES INVOLVING MASS

MASS DENSITY, ρ.

MASS PER UNIT VOLUME

SPECIFIC WEIGHT, γ.

WEIGHT PER UNIT VOLUME

TWO ARE RELATED BY ACCELERATION

$$\gamma = \rho g$$

SPECIFIC GRAVITY, S (S.G.)

$$S.G. = \frac{\gamma_{FLUID}}{\gamma_{WATER}}$$

SCRIPT

• DEFINE COMPRESSIBILITY

· NOTE ALSO TEMP. DEPENDENT

· EVEN WATER, WHICH IS USUALLY TREATED AS INCOMPRESSIBLE CHANGES DENSITY WITH TEMP. CHANGE.

(pg 33-35)

BOARD

IN SOME FLUIDS (GASSES)

ρ IS A FUNCTION OF APPLIED NORMAL STRESS

$$\rho = \rho(p)$$

SUCH FLUIDS ARE CALLED COMPRESSIBLE.

IF BULK COMPRESSIBILITY IS SMALL

$$\frac{d\rho}{dp} \sim \text{SMALL}$$

THE FLUID IS INCOMPRESSIBLE.

SCRIPT	BOARD
HEAT/THERMAL PROPERTIES	FLUID PROPERTIES INVOLVING HEAT
SP. HEAT DEPENDS ON SYSTEM OF UNITS, AND UNIT MASS CHOSEN.	SPECIFIC HEAT, c
TYP. $\frac{Btu}{lbm}$; $\frac{kJ}{kg}$	HEAT AMOUNT THAT IS ADDED TO A UNIT MASS OF FLUID TO RAISE TEMPERATURE ONE DEGREE
SP. HEAT ALSO DEPENDS ON IF ΔT INVOLVES PHASE CHANGE	SPECIFIC INTERNAL ENERGY, u
	ENERGY SUBSTANCE POSSESSES BECAUSE OF ITS STATE OF MOLECULAR ACTIVITY
LIQUID $\rightarrow$ GAS (VAPORIZATION)	SPECIFIC ENTHALPY, $h = u + \frac{p}{\rho}$
GAS $\rightarrow$ LIQUID (FUSION)	ENERGY A SUBSTANCE HAS BECAUSE OF INTERNAL ENERGY AND APPLIED PRESSURE
(pg 51)	

SCRIPT	BOARD
IDEAL GAS LAW IS AN EQUATION OF STATE	$p\forall = nRT$
(pg 30, Figure 2.3)	# moles
	$p\forall = \frac{m}{M}RT$
	MASS
	MOLECULAR "WEIGHT"
	c_v – CONSTANT VOLUME SP. HEAT: SP. HEAT AS VOLUME IS HELD CONSTANT
	c_p – CONSTANT PRESSURE S.P. HEAT: S.P. HEAT AS PRESSURE HELD CONSTANT

SCRIPT

- VISCOUS FLUIDS

ASK "WHAT IS A FLUID?"

A SUBSTANCE THAT DEFORMS CONTINUOUSLY UNDER APPLIED SHEAR STRESS

EXAMINE "RATE" DEFORMATION

NOTATION:

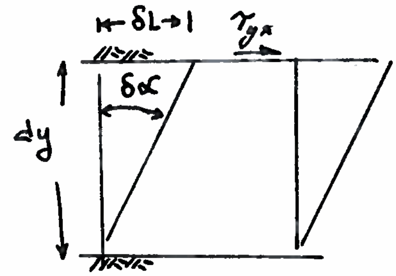
V – VELOCITY

$\forall$ – VOLUME

(pg 36–38)

BOARD

VISCOUS FLUIDS



δF; δV

$$\tau_{yx} = \lim_{\delta A \to 0} \frac{\delta F}{\delta A} = \frac{dF}{dA}$$

RATE OF DEFORMATION IS

$$\lim_{\delta t \to 0} \frac{\delta \alpha}{\delta t} = \frac{d\alpha}{dt}$$

SCRIPT

- DISPLACEMENT = VELOCITY * TIME

- USE SOME CALCULUS AND TRIGONOMETRY

- CONSIDER $\delta\alpha$ SMALL

$\tan(\alpha) = \alpha$ FOR SMALL α

BOARD

RATE IN TERMS OF ELEMENT GEOMETRY

$\delta L = \delta V \delta t$ ~~(displacement)~~

$\delta L = \delta y \, \delta\alpha$

$$\tan(\delta\alpha) = \frac{\delta L}{\delta y}$$

$\therefore \dfrac{\delta V}{\delta y} = \dfrac{\delta\alpha}{\delta t}$ AND IN THE LIMIT

$$\frac{d\alpha}{dt} = \frac{dV}{dy}$$

THE RATE $\dfrac{d\alpha}{dt}$ IS RELATED TO THE VELOCITY PROFILE.

IF THE RATE $\frac{d\alpha}{dt}$ IS PROPORTIONAL TO APPLIED SHEAR STRESS FLUID IS CALLED NEWTONIAN

(pg 35 – 37)

BOARD

IF $\frac{d\alpha}{dt} \propto \tau_{yx}$

THEN $\tau_{yx} \propto \frac{dV}{dy}$ (NEWTONIAN)

THE CONSTANT OF PROPORTIONALITY IS CALLED ABSOLUTE VISCOSITY, μ

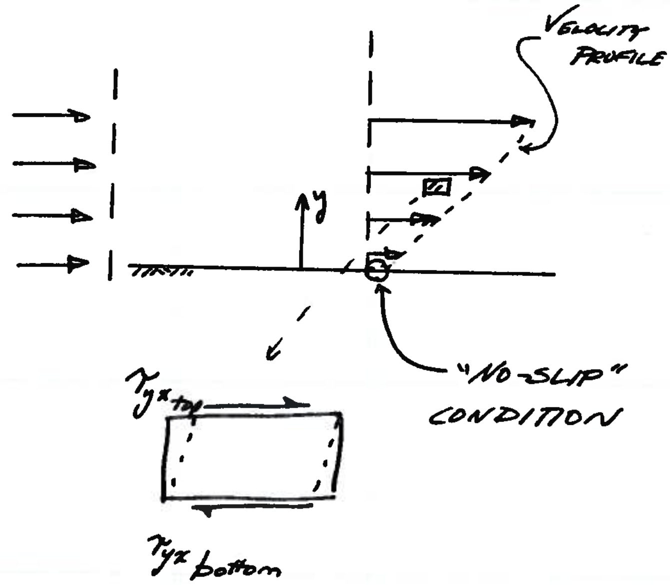
$$\tau_{yx} = \mu \frac{dV}{dy}$$

IF NOT PROPORTIONAL THEN NON-NEWTONIAN

BOARD

TYP. POWER-LAW MODEL APPLIED

$$\tau_{yx} = \underbrace{k\left(\frac{dV}{dy}\right)^{n-1}}_{\text{APPARENT VISCOSITY}} \frac{dV}{dy}$$

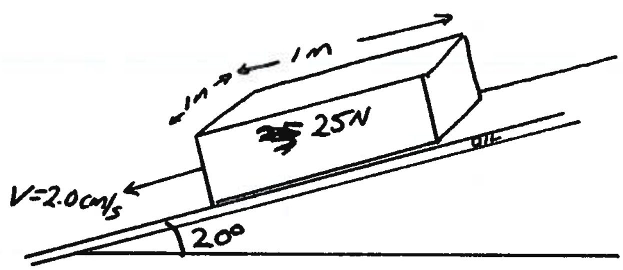
SCRIPT	BOARD
• VISCOUS EFFECTS CAUSE A VELOCITY GRADIENT (PROFILE) TO DEVELOP • SLOPE OF THE PROFILE IS RELATED TO SHEAR • SOMETIMES ALSO CALLED VELOCITY GRADIENT • NO SLIP IS "DEDUCED" FROM EXPERIMENTS, AN ASSUMPTION THAT RELATIVE VELOCITY VANISHES AT CONTACT	
SCRIPT • WORK SLIDING BLOCK PROBLEM • NOTE BOOK EXAMPLES 2.1 & 2.2 ARE CLASSIC (AND FAIR GAME) EXAM	WORK EXAMPLE 2.2 IN CLASS. WORK VISCOUS CLUTCH EXAMPLE (PROVIDE HANDOUT OF PROBLEM STATEMENT)

EXAMPLE 2.2

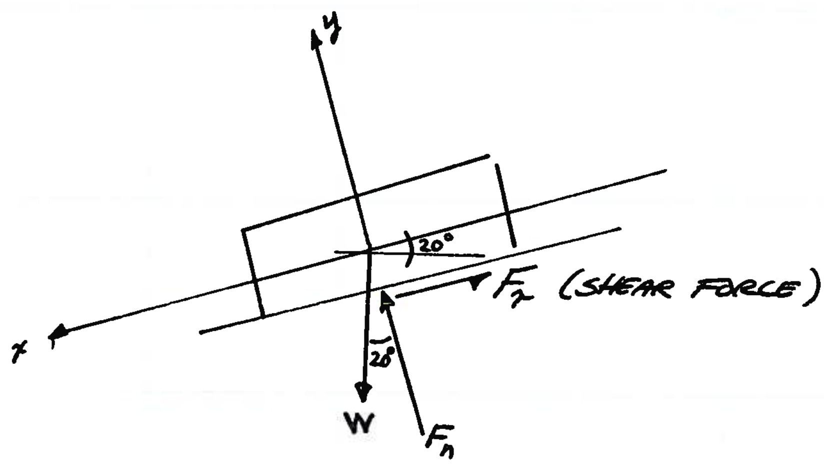
A 1m x 1m BLOCK WEIGHING 25N SLIDES DOWN A 20° INCLINED RAMP AT SPEED 2.0 cm/s.

THE BLOCK IS LUBRICATED BY A THIN FILM OF OIL WITH VISCOSITY OF 0.5 N·s/m². HOW THICK IS THE OIL?

SKETCH

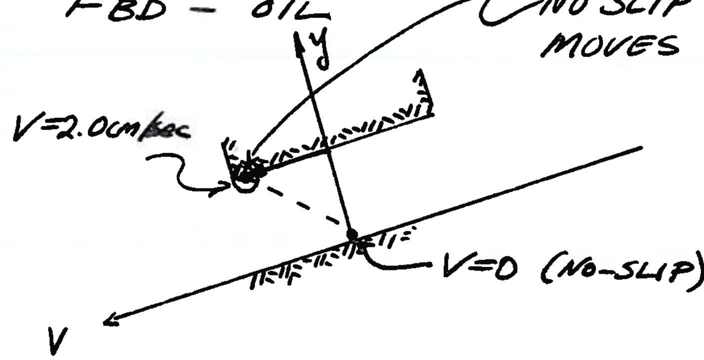


FBD – BLOCK



FBD – OIL

NO SLIP HERE; BLOCK MOVES 2cm/s; OIL MOVES 2cm/s



KNOWN

$W_{BLOCK} = 25N$ $\mu_{OIL} = 0.5 N\cdot s/m^2$

ANGLE $= 20°$ $A_{CONTACT} = 1m \times 1m = 1m^2$

GOVERNING EQUATION(S)

~~$\Sigma F = a$~~ $\Sigma \underline{F} = m\underline{a}$ (FORCES: NEWTON'S 2^{ND} LAW)

$\tau = \mu \frac{dV}{dy}$ (DEFINITION OF VISCOSITY)

$\tau = \frac{F}{A}$ (DEFINITON OF SHEAR STRESS)

UNKNOWN (FIND)

y: THICKNESS OF OIL IN VELOCITY PROFILE.

SOLUTION

ANALYZE BLOCK

$\Sigma F_x = m\cancel{a_x}$ $=0$; CONSTANT VELOCITY

$\therefore$

$\Sigma F_x = W \sin 20° - F_\tau = 0$

$F_\tau = W \sin 20° = \tau \cdot A_{BLOCK}$

ANALYZE OIL

ASSUME NEWTONIAN

$\tau = \mu \frac{dV}{dy}$

MULTIPLY BY CONTACT AREA

$\tau A = \mu \frac{dV}{dy} A$

~~SOLVE~~ SUBSTITUTE $W\sin 20°$ FOR τA

$$W\sin 20° = \mu \frac{dV}{dy} A$$

REARRANGE TO ISOLATE dy

$$dy = \frac{\mu\, dV A}{W\sin 20°}$$

SUBSTITUTE NUMERICAL VALUES; KEEP UNITS

$$dy = \frac{0.05\,\cancel{N}\cdot s/\cancel{m^2} \cdot 0.02\,m/\cancel{s} \cdot 1\,\cancel{m^2}}{25\,\cancel{N}\, \sin 20°}$$

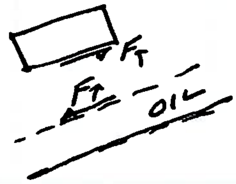
$$= 0.000\,177\ m$$

$$= \underline{0.18\,mm} \longleftarrow dy,$$

OIL THICKNESS

DISCUSSION

- PROBLEM REQUIRED USE OF ENGINEERING MECHANICS TO FIND EQUILIBRIUM CONDITIONS FOR THE BLOCK
- IMPLICIT NEWTON'S 3RD LAW



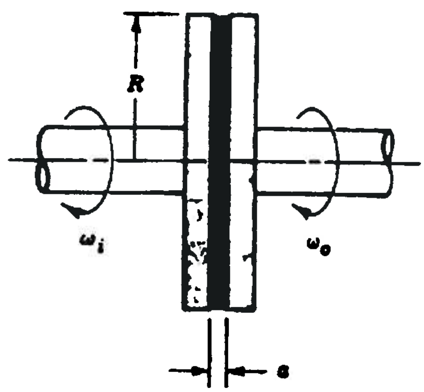
- NO SLIP CONDITION <u>TOP</u> AND <u>BOTTOM</u>
- ~~ASSUMED~~ NEWTONIAN; NOT ENOUGH INFORMATION FOR NON-NEWTONIAN

EXAMPLE

PROBLEM STATEMENT

A viscous clutch is to be made from a pair of closely spaced parallel disks enclosing a thin layer of viscous liquid. Develop algebraic expressions for the torque and the power transmitted by the disk pair, in terms of liquid viscosity, μ, disk radius, R, disk spacing, a, and the angular speeds: ω_i of the input disk and ω_o of the output disk. Also develop expressions for the slip ratio, $s = \Delta\omega/\omega_i$, in terms of ω_i and the torque transmitted. Determine the efficiency, η, in terms of the slip ratio.

SKETCH



KNOWN

ω_i – INPUT ANGULAR SPEED (FREQUENCY)

ω_o – OUTPUT ANGULAR SPEED

R – DISK RADIUS

a – SPACING

μ – VISCOSITY

GOVERNING EQUATIONS

$\Sigma M_o = 0$ (CONSTANT ANGULAR VELOCITY)

$\tau(r) = \mu \dfrac{dV(r)}{dy}$ (DEFINITION VISCOSITY)

$P = \dfrac{W}{t} = \dfrac{F \cdot d}{t}$ (DEFINITION OF POWER)

UNKNOWN (FIND)

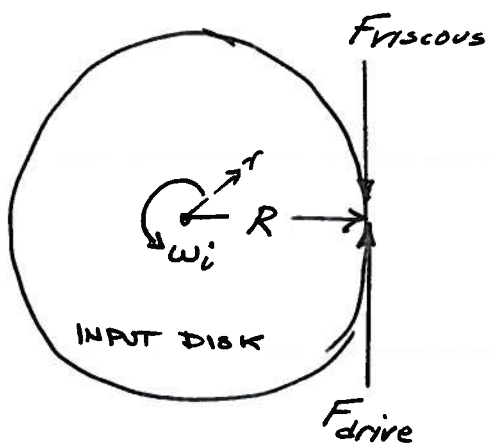
$T_{TRANSMITTED}$

$S = \frac{\omega_i - \omega_o}{\omega_i}$ (SLIP RATIO)

$\eta = \frac{P_{OUT}}{P_{IN}}$ (EFFICIENCY)

SOLUTION

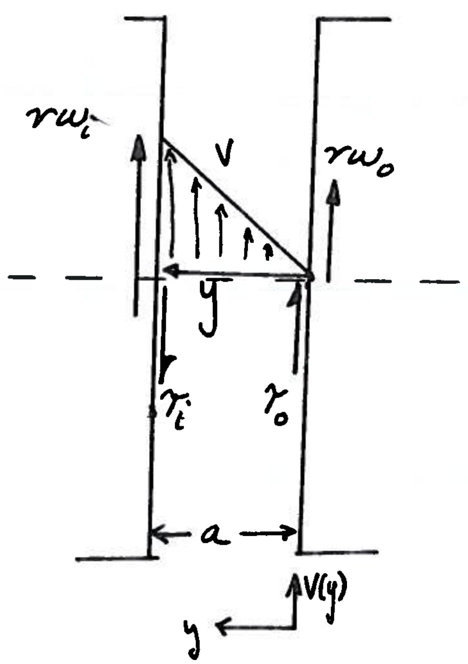
ANALYZE DRIVE DISK



$\Sigma M_o = \dot{H}_o = 0$ CONSTANT ω

$\underbrace{F_{drive} \cdot R}_{\text{DRIVE TORQUE}} = \underbrace{F_{VISCOUS} \cdot R}_{\text{VISCOUS TORQUE}}$

ANALYZE TANGENTIAL VELOCITIES ON EACH DISK



$\tau(r) = \mu \frac{dV(r)}{dy}$

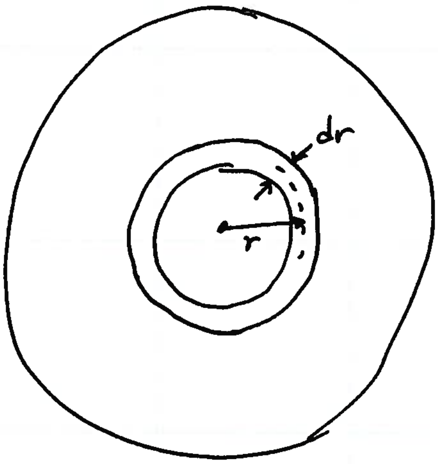
$V_t(r) = r(\omega_i - \omega_o) = r\Delta\omega$

$\frac{dV_t(r)}{dy} = \frac{\Delta V_t(r)}{\Delta y} = \frac{r\Delta\omega}{a}$

RECALL

$\tau = \frac{F}{A} \therefore \tau A = F$

NOW NEED AREA



$$dA = 2\pi r\,dr$$

$$dF = \tau\,dA = \mu \frac{r\Delta\omega}{a} \cdot 2\pi r\,dr$$

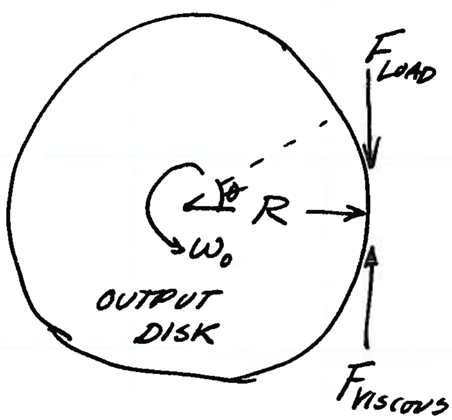
$$dT = r\,dF = \mu \frac{r^3\Delta\omega}{a} 2\pi\,dr$$

$$\int dT = \int_0^R \frac{\mu\Delta\omega 2\pi}{a} r^3\,dr$$

$$T = \frac{\mu\Delta\omega 2\pi}{a} \frac{R^4}{4}$$

$$T_{VISCOUS} = \frac{\pi\mu\Delta\omega R^4}{2a} = \underline{\underline{T_{DRIVE}}} \longleftarrow T_{TRANS.}$$

NOW FIND POWER, ANALYZE OUTPUT DISK



WORK DONE BY $F_{VISCOUS}$

$$W_{VISCOUS} = F_{VISCOUS} \cdot R\theta$$

$$P_{VISCOUS} = F_{VISCOUS} \cdot R\dot{\theta}$$

$$\underline{\underline{P = \frac{\pi\mu\omega_o\Delta\omega R^4}{2a}}} \longleftarrow P_{TRANS}$$

RECALL

$$P = \frac{F \cdot d}{t} = FV$$

EXPRESS IN TERMS OF TORQUE

$$\Delta w = \frac{T \cdot 2a}{\pi N R^4}$$

$$\therefore \quad s = \frac{\Delta w}{w_i} = \underline{\underline{\frac{T \cdot 2a}{\pi N w_i R^4}}} \longleftarrow s$$

EFFICIENCY

$$\frac{P_{OUT}}{P_{IN}} = \frac{\left(\frac{\cancel{\pi N} w_o \cancel{\Delta w R^4}}{\cancel{2a}}\right)}{\left(\frac{\cancel{\pi N} w_i \cancel{\Delta w R^4}}{\cancel{2a}}\right)} = \frac{w_o}{w_i}$$

$$s = \frac{w_i - w_o}{w_o}$$

$$w_i s = w_i - w_o$$

$$\therefore \quad w_o = w_i - w_i s = w_i (1 - s)$$

$$\eta = \frac{w_i(1-s)}{w_i} = \underline{\underline{1 - s}} \longleftarrow \eta$$

DISCUSSION

- FAIRLY COMPLEX ANALYSIS FOR AN AUTOMATIC TRANSMISSION. INVOLVES TWO GEOMETRIES; THE RADIAL IN THE PLANE OF THE DISKS AND A LINEAR GEOMETRY BETWEEN DISKS
- NEEDED TO INTERGATE TO OBTAIN RESULT; IN RADIAL GEOMETRY.

NAME CLEVELAND DATE 22JAN14
COURSE CE3305 SHEET 1 OF 4

SCRIPT

QUIZ#2
ROLL SHEET

ELASTICITY IS AMOUNT OF VOLUME DEFORMATION FOR GIVEN CHANGE IN APPLIED PRESSURE.

SOMETIMES CALLED A MODULUS OF COMPRESSIBILITY OF ELASTICITY

SURFACE TENSION IS ~~FORCE~~ WORK PER UNIT AREA REQUIRED TO SEPARATE TWO FLUIDS.

DIMENSIONALLY IT IS EXPRESSED AS FORCE PER UNIT LENGTH

SURFACE TENSION IS ONE REASON WHY LIQUIDS CAN RISE UP CAPILLARY TUBES OF ~~RO~~ POROUS MATERIALS

BOARD

FLUID PROPERTIES

ELASTICITY

$$E_{\forall} = -\frac{dp}{d\forall}\cdot\forall \quad \text{(EXTENSIVE)}$$

$$E_{\forall} = \frac{-dp}{d\rho}\rho \quad \text{(INTENSIVE)}$$

SURFACE TENSION

σ

USUALLY MEASURED WITH A RING TENSIOMETER (PROBLEM 2.67)

SCRIPT

SURFACE TENSION CONTROLS HOW LIQUIDS SPREAD OR BEAD UP.

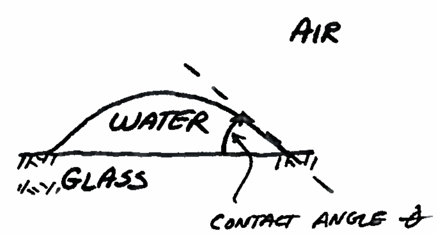
DETERGENTS CHANGE SURFACE TENSION AND HENCE

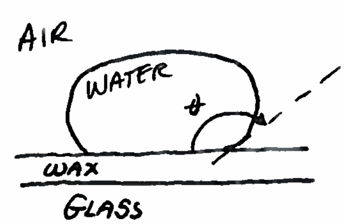
WETTING PROPERTIES

DEMO: WETTING & NON-WETTING

BOARD

SURFACE TENSION DETERMINES CONTACT ANGLE BETWEEN THREE PHASES





$\theta < \pi/2$; WETTING FLUID

$\theta > \pi/2$; NON-WETTING FLUID

SCRIPT

CAPILLARY RISE IS THE TENDENCY OF A LIQUID TO RISE UP IN NARROW TUBES – IT IS HOW ABSORBENTS WORK FOR FUEL SPILLS AND SUCH.

CAN EXPLAIN USING A SIMPLE FORCE BALANCE

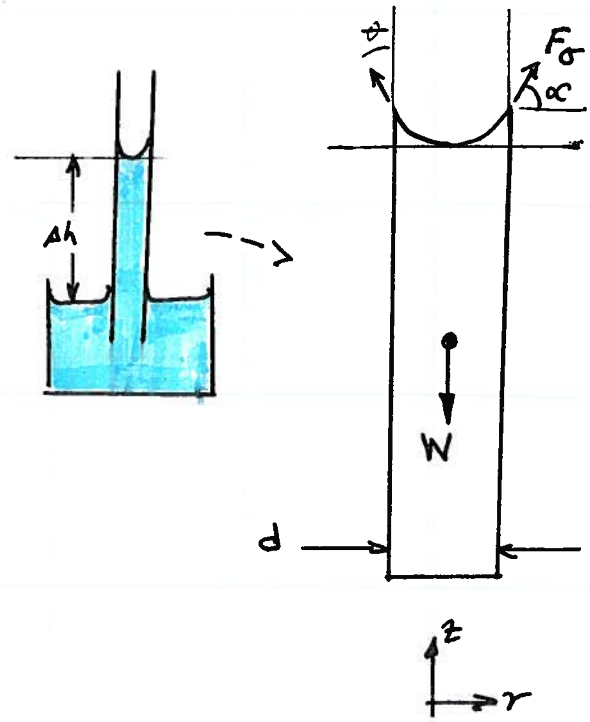
SKETCH THE SITUATION

FBD OF JUST COLUMN IN CAPILLARY TUBE.

I CHOOSE α TO ILLUSTRATE ALTERNATE POINT OF VIEW.

BOARD

CAPILLARY RISE – RELATED TO WETTING.



SCRIPT

ALGEBRA (IF TIME STRESS SKIP TO RESULT)

$$\sigma\pi d\sin\alpha = \frac{\pi d^2}{4}\Delta h \rho g$$

$$\frac{4\sigma\cancel{\pi}\cancel{d}\sin\alpha}{\cancel{\pi}d^{\cancel{2}}\rho g} = \Delta h$$

$$\Delta h = \frac{4\sigma\sin\alpha}{\rho g d} = \frac{4\sigma\sin\alpha}{\gamma d}$$

CONTACT ANGLE FOR WATER IS NEARLY $\pi/2$

$\therefore \sin(\alpha) \approx 1$

BOARD

WRITE A FORCE BALANCE

$$F_\sigma = \sigma L = \sigma\pi d$$

BUT NEED COMPONENT OF FORCE IN +Z DIRECTION!

$$\sum F_z = m\overset{=0}{\cancel{a_z}} = F_\sigma\sin\alpha - W$$

$$0 = \sigma\pi d\sin\alpha - \underbrace{\frac{\pi d^2}{4}\Delta h\rho g}_{\text{WEIGHT OF WATER COLUMN}}$$

SOLVE FOR Δh

$$\Delta h = \frac{4\sigma\sin\alpha}{\gamma d}$$

SCRIPT

CAN USE CAPILLARY RISE EQUATION TO ESTIMATE Δh.

LIKEWISE CAN USE TO ESTIMATE σ, GIVEN Δh.

IF CAN FIND 2 TUBES DO DEMONSTRATION USING WATER & WATER + DETERGENT

BOARD

NOW ESTIMATE CAPILLARY RISE FOR REGULAR WATER

$$\Delta h \approx \frac{4\sigma}{\gamma d}$$

PROBLEM

FIND Δh FOR WATER IN A GLASS TUBE $d = 1.6$ mm AT 20°C

SKETCH

KNOWN

~~$\Delta h \approx \frac{4\sigma}{\gamma d}$~~

$d = 0.0016$ m

$\sigma = 0.0728$ N/m

$\gamma = 9800$ N/m³

SCRIPT

BOARD

GOVERNING EQUATIONS

$$\Delta h \approx \frac{4\sigma}{\gamma d}$$

UNKNOWN

Δh

SOLUTION

APPLY GOVERNING EQUATION USING SUPPLIED (LOOK-UP) VALUES

$$\Delta h = \frac{4(0.0728\ \mathrm{N/m})}{(9800\ \mathrm{N/m^3})(0.0016\ \mathrm{m})}$$

$$= 0.0186\ \mathrm{m} = 18.6\ \mathrm{mm}$$

DISCUSSION

MM → M IS VITAL.

SCRIPT	BOARD
SUMMARIZE MATERIALS IN MODULE 1. ESSENTIALLY CHAPTERS 1 & 2.	SUMMARY "MODULE 1" • DEFINED A FLUID • DISCUSSED IDEAS OF CONTINUUM PARTICLE • DIMENSIONS & UNITS • UNIT CONVERSIONS • EQUATION OF STATE FOR GASSES » DIMENSIONAL HOMOGENITY (ON YOUR OWN; π-GROUPS)
	• FLUID PROPERTIES • EXTENSIVE • INTENSIVE » SYSTEMS (ON YOUR OWN) • DENSITY • VISCOSITY $\tau ; \mu ; \frac{dV}{dy}$ $\tau = \mu \frac{dV}{dy}$