CIVE 4311 Engineering Design
Fluid Mechanics
Lecture 014

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1 Likely Topics

Fluid Mechanics on the FE exam will likely focus on the following topics.

1. Viscosity, density, pressure and other fluid properties.
2. Forces on submerged bodies, buoyancy, and pressure changes in hydrostatic fluids. This topic section would include manometers.
3. Conservation principles; mostly mass. linear momentum, and energy. Possibly angular momentum, but I would advise against overemphasis on angular momentum (its important, but problems of any consequence would take too long).
4. Pipe flow — need to know how to use Moody chart for head loss given flow and dimensions, friction factors given head loss and dimensions.
5. Open channel flow — likely only cursory coverage. Know definitions, Manning's and Chezy equations.
6. Pumping — know added head formulas. NPSH unlikely, but should know how to read a pump curve. Know system curves (how to interpret).
7. Pipe networks — only simplest are likely. Conservation of mass at a junction (node). Conservation of energy around any closed loop. Energy at a node is unique (path independent).

Most fluid references in NCEES supplied reference are on pages 44-55.

2 Fluid properties

Important properties are:

Density. $\rho = \frac{m}{v}$.

Specific volume. $v = \frac{1}{\rho}$.

Specific weight. $\gamma = \rho\ g$.

Specific gravity. $SG_l = \frac{\rho_l}{\rho_w}$

Pressure. Pressure is the scalar of normal stress in a fluid. Generally shear stress are very small (zero in an inviscid fluid). Pressure is either absolute, gage, or vacuum. Vacuum (negative pressures relative to atmospheric) are expressed as positive vacuum — this concept is the only place you are likely to make a mistake. If the problem statement has the word 'vacuum', proceed cautiously. Typical expressions are:

$p_{abs} = p_{gage} + p_{atm}$ and

$p_{abs} = -p_{vacuum} + p_{atm}$.

Viscosity. If the fluid is viscous (all real fluids) then there will be some shear stress. The relationship of the rate of shear deformation to applied stress (force per area) is the fluid viscosity.

$\tau = \mu\ \frac{dv}{dy}$ The term μ is the absolute viscosity. If the relationship is linear (as here) the fluid is called a Newtonian fluid. If the rate term is raised to some power other than one, the fluid is non-Newtonian. All real fluids are non-Newtonian, but many (water, ammonia, air) are well approximated by the Newtonian model and are treated as Newtonian for all practical purposes.

Kinematic viscosity is the ratio of the absolute viscosity to the fluid density.

Surface tension is the amount of work required to break a fluid apart at its interface. It is expressed as force per distance. Its usual symbol is σ.

Capillary rise is the rise of a fluid into a small diameter tube caused by an imbalance in adhesive and cohesive forces — surface tension plays a role. The typical formula is

$h_c = \frac{4\sigma cos\beta}{\gamma d}$

2.1 Problems

22-5(4)

22-5(5)

22-6(7)

22-6(8)

3 Fluid Statics

Fluid statics is concerned with fluid behavior at zero acceleration.

Hydrostatic pressure is pressure in a fluid at zero acceleration. Usually it is referenced to the fluid surface (interface with another fluid where pressure is known).

$p = \gamma\ h_d$ where h_d is depth into the fluid from the interface (free surface). This relationship must be memorized. Pressure variation is linear with depth — this fact is used in analyzing forces.

Manometer and Barometer are fluid systems that measure ΔP. In either system, moving down in a fluid increases pressure, moving up in a fluid decreases pressure. Additionally a fluid transmits pressure undiminished throughout the system.

3.1 Problems

23-5(2)

Submerged Bodies Expect several of these problems — they are easy to do well, and easy to mess up. Principal trick is to take advantage of hydrostatic pressure distribution and buoyancy to resolve vertical and horizontal components of forces, then answer the questions. Avoid integration at all costs (on the FE it wastes time). The formulas in the review book and NCEES are slow - here we will learn a valuable shortcut.

Center of pressure is where the resultant of the vertical and horizontal component of force act on asubmerged body. Horizontal component acts through centroid of pressure prism (distributed force). Vertical component acts through centroid of displaced liquid above object.

Bouyancy force is the weight of displaced fluid.

3.2 Problems

23-5(2)

23-6(3)

23-6(4)

23-6(5)

23-7(7)

4 Fluid Dynamics

Behavior of fluids than may be accelerating.

Conservation of Mass. Mass flows are conserved.

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

Also used in velocity and/or discharge form as

$\rho_1 A_1 v_1 = \rho_2 A_2 v_2$ and/or $\rho_1 Q_1 = \rho_2 Q_2$

If incompressible, then ρ is a constant and conservation of flux is sufficient.

Conservation of Energy. Fluid system energy is comprised of pressure, velocity, and gravitational potentials (heads).

$h_{total} = \frac{p}{\gamma} + \frac{v^2}{2g} + z$

Hydraulic Grade Line is a plot of the pressure head in a system referenced to some datum (i.e. $z = 0$).

Energy Grade Line is a plot of the pressure and velocity head in a system.

Bernoulli's Equation In absence of energy losses (friction) the total head (energy) in a system is a constant.

$\frac{p_1}{\gamma} + \frac{v_1^2}{2g} + z_1 = \frac{p_2}{\gamma} + \frac{v_2^2}{2g} + z_2$

Energy Equation with Losses. Energy losses (additions) are handled by adding term to each side of Bernoulli equation.

$\frac{p_1}{\gamma} + \frac{v_1^2}{2g} + z_1 + h_{addedfrom1to2} = \frac{p_2}{\gamma} + \frac{v_2^2}{2g} + z_2 + h_{lostfrom1to2}$

Usually the added and lost are written with the subscripts a and f.

$\frac{p_1}{\gamma} + \frac{v_1^2}{2g} + z_1 + h_a = \frac{p_2}{\gamma} + \frac{v_2^2}{2g} + z_2 + h_f$

Reynolds Number is ratio of inertial to viscous forces. $Re = \frac{\rho VD}{\mu} = \frac{VD}{\nu}$. It is used to characterize flow (turbulent, transition, laminar) and to compute frictional losses.

Frictional Loss - Darcy Equation. $h_f = f \, \frac{L}{D} \, \frac{V^2}{2g}$ Friction factors tabulated for different materials based on roughness height. Usually determined from Moody Chart.

If laminar flow then $f = \frac{64}{Re}$.

If non-circular use hydraulic radius to compute hydraulic diameter (equivalent diameter).

$R_h = \frac{A}{P_w}$

$D_h = 4 \times R_h$

Momentum The conservation of linear momentum for a fluid is the statement that the sum of external forces on a fluid element is equal to the change in linear momentum of the fluid element. This principle is used to compute thrusts and similar forces. It does not apply to angular momentum within a fluid.

$\sum F = \frac{d \; mV}{dx}$

In practice it is easiest to compute momentum entering, momentum leaving and solve for force.

4.1 Problems

24-11(2)

24-12(4)

24-14(6)

24-15(9)

24-15(10)

24-15(11)

24-15(12)

24-15(20)