CVEN 311-501

Fluid Dynamics

Final Exam

December 5, 2008, 10:00 am - 12:00 pm in CE 110

Name: _______________________________

UIN: _______________________________ 

Instructions:

Fill in your name and UIN in the space above. There should be 12 pages including this one.

The exam is closed book, and only three double-sided sheets of notes and a calculator are permitted. No collaboration with others!

For multiple choice questions, choose the single, best answer and mark your answer on the sheets provided.

For short answer and workout problems, write down all general equations used and intermediate algebraic steps. Show all your work. Failure to do so will result in a lower score. Write your solutions in the space provided or attached additional pages as needed.

You have 120 minutes to complete the exam.

Grading:

<table>
<thead>
<tr>
<th>Problems</th>
<th>Points Possible</th>
<th>Points Earned</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple Choice (1-10)</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>Workout (11-12)</td>
<td>60</td>
<td></td>
</tr>
</tbody>
</table>

Grade: _____________ / 100

Certification:

I certify by my signature below that the work I am submitting is my own.

“An Aggie does not lie, cheat or steal, or tolerate those who do.”

Signature: _______________________________
### Properties of Water

<table>
<thead>
<tr>
<th>Property</th>
<th>Symbol</th>
<th>SI Units</th>
<th>BG Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>ρ</td>
<td>1000 kg/m³</td>
<td>1.941 slug/ft³</td>
</tr>
<tr>
<td>Gravity</td>
<td>g</td>
<td>9.81 m/s²</td>
<td>32.17 ft/s²</td>
</tr>
<tr>
<td>Dynamic viscosity</td>
<td>μ</td>
<td>0.00152 Pa·s</td>
<td>3.22 × 10⁻⁵ lb·s/ft²</td>
</tr>
<tr>
<td>Specific weight</td>
<td>γ</td>
<td>9810 N/m³</td>
<td>62.4 lb/ft³</td>
</tr>
</tbody>
</table>

### Useful Equations

1. \[ F_R = \gamma h_c A \]  
2. \[ y_R = \frac{I_{xc}}{\gamma_c A} + y_c \]  
3. \[ \frac{D\vec{v}}{Dt} = \frac{\partial\vec{v}}{\partial t} + \vec{v} \cdot \nabla \vec{v} \]  
4. \[ \int_{CS} \vec{v} (\rho \vec{v} \cdot \hat{n}) dA = \sum F \]  
5. \[ \frac{P_{out}}{\gamma} + \frac{v_{out}^2}{2g} + z_{out} = \frac{P_{in}}{\gamma} + \frac{v_{in}^2}{2g} + z_{in} + h_Q + h_S - h_L \]  
6. \[ h_S = \frac{\dot{W}}{\gamma Q} \]

### Geometric Properties of Some Common Shapes

- **(a) Rectangle**
  - \[ A = bh \]
  - \[ I_x = \frac{1}{12} bh^3 \]
  - \[ I_y = \frac{1}{12} ab^3 \]
  - \[ I_{xc} = 0 \]

- **(b) Circle**
  - \[ A = \pi R^2 \]
  - \[ I_x = I_y = \frac{\pi R^4}{4} \]
  - \[ I_{xc} = 0 \]

- **(c) Semicircle**
  - \[ A = \frac{4R^2}{3\pi} \]
  - \[ I_x = 0.1098R^4 \]
  - \[ I_y = 0.3927R^4 \]
  - \[ I_{xc} = 0 \]

- **(d) Triangle**
  - \[ A = \frac{ab}{2} \]
  - \[ I_x = \frac{ba^3}{36} \]
  - \[ I_{yc} = \frac{bc^3}{72} (b - 2a) \]
### TABLE 8.2

Loss Coefficients for Pipe Components \( h_L = K_L \frac{V^2}{2g} \) (Data from Refs. 5, 10, 27)

<table>
<thead>
<tr>
<th>Component</th>
<th>( K_L )</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>a. Elbows</strong></td>
<td></td>
</tr>
<tr>
<td>Regular 90°, flanged</td>
<td>0.3</td>
</tr>
<tr>
<td>Regular 90°, threaded</td>
<td>1.5</td>
</tr>
<tr>
<td>Long radius 90°, flanged</td>
<td>0.2</td>
</tr>
<tr>
<td>Long radius 90°, threaded</td>
<td>0.7</td>
</tr>
<tr>
<td>Long radius 45°, flanged</td>
<td>0.2</td>
</tr>
<tr>
<td>Regular 45°, threaded</td>
<td>0.4</td>
</tr>
<tr>
<td><strong>b. 180° return bends</strong></td>
<td></td>
</tr>
<tr>
<td>180° return bend, flanged</td>
<td>0.2</td>
</tr>
<tr>
<td>180° return bend, threaded</td>
<td>1.5</td>
</tr>
<tr>
<td><strong>c. Tees</strong></td>
<td></td>
</tr>
<tr>
<td>Line flow, flanged</td>
<td>0.2</td>
</tr>
<tr>
<td>Line flow, threaded</td>
<td>0.9</td>
</tr>
<tr>
<td>Branch flow, flanged</td>
<td>1.0</td>
</tr>
<tr>
<td>Branch flow, threaded</td>
<td>2.0</td>
</tr>
<tr>
<td><strong>d. Union, threaded</strong></td>
<td>0.08</td>
</tr>
<tr>
<td><strong>e. Valves</strong></td>
<td></td>
</tr>
<tr>
<td>Globe, fully open</td>
<td>10</td>
</tr>
<tr>
<td>Angle, fully open</td>
<td>2</td>
</tr>
<tr>
<td>Gate, fully open</td>
<td>0.15</td>
</tr>
<tr>
<td>Gate, ( \frac{1}{4} ) closed</td>
<td>0.26</td>
</tr>
<tr>
<td>Gate, ( \frac{1}{2} ) closed</td>
<td>2.1</td>
</tr>
<tr>
<td>Gate, ( \frac{3}{4} ) closed</td>
<td>17</td>
</tr>
<tr>
<td>Swing check, forward flow</td>
<td>2</td>
</tr>
<tr>
<td>Swing check, backward flow</td>
<td>( \infty )</td>
</tr>
<tr>
<td>Ball valve, fully open</td>
<td>0.05</td>
</tr>
<tr>
<td>Ball valve, ( \frac{1}{4} ) closed</td>
<td>5.5</td>
</tr>
<tr>
<td>Ball valve, ( \frac{3}{4} ) closed</td>
<td>210</td>
</tr>
</tbody>
</table>

*See Fig. 8.32 for typical valve geometry.*
Laminar flow → Critical zone → Transition zone → Complete turbulence, rough pipes, $R > 3500/r$, $1/\sqrt{f} = 1.14 - 2 \log r$

### Darcy-Weisbach friction factor $f$

- Smooth pipes, $r = 0$
  
  \[ f = \frac{64}{R} \]

- Hagen–Poisseuille equation
  \[ R \leq 2300, f = \frac{64}{R} \]

- Colebrook equation, $R \geq 2300$
  \[ 1/\sqrt{f} = -2 \log(r/3.7 + 2.51/(R \sqrt{f})) \]

- Continuity equation, $Q = AV$
  \[ A = \pi D^2/4, V = 4Q/(\pi D^2) \]

### Fluid at 20°C

- Water
  - Density: $1.003 \times 10^{-6}$ kg/m$^3$
  - Dynamic viscosity: $1.03 \times 10^{-6}$ Pa·s

- Air (101.325 kPa)
  - Density: $1.18 \times 10^{-3}$ kg/m$^3$
  - Dynamic viscosity: $1.5 \times 10^{-5}$ Pa·s

### Relative roughness $r = D/\varepsilon$

- Smooth pipes, $r = 0$
  \[ 1/\sqrt{f} = 2 \log(R \sqrt{f}) - 0.8 \]

- Metzger & Willard, Inc.
  [http://www.metzgerwillard.com](http://www.metzgerwillard.com)
Multiple Choice Questions (4 points each for total of 40 points)

For each of the following questions, circle the answer that is most appropriate or closest numerically to your answer. Be sure to clearly mark only one answer. Multiple selections will be graded as zero.

1. Which of the following is not true of a fluid?
   a. Deforms continuously when acted on by a shearing stress of any magnitude
   b. Can have a dynamic viscosity that increases as the applied shear stress increases
   c. Can be treated as a continuous substance under the continuum hypothesis
   d. Resists a shear stress until a finite value above which the substance deforms continuously when acted on by any larger shearing stress
   e. Cannot have a negative absolute pressure

2. Shear stresses in a fluid are proportional to
   a. Density
   b. Viscosity
   c. Surface Tension
   d. Compressibility
   e. Specific Gravity

3. Which of the following statements is not true about the Bernoulli equation?
   a. Is applied to a control volume
   b. Assumes an inviscid fluid
   c. Assumes an incompressible fluid
   d. Is applied along a streamline
   e. Is derived for steady flows

4. Which of the following statements is true about any control volume
   a. A control volume cannot change shape or size over time
   b. Control volumes move with a fixed set of fluid particles such that the control volume always contains the same fluid particles
   c. Control volume analysis can only be used to solve steady flow problems
   d. A control volume is always equivalent to a material system
   e. A control volume is an arbitrarily defined region of space through which fluid may pass in and out

5. A student tests a wind turbine in the laboratory using suspended particles distributed throughout the flow field to visualize the flow. The wind tunnel is turbulent so that the flow is unsteady. What line will each individual particle follow?
   a. Timeline
   b. Pathline
   c. Dateline
   d. Streakline
   e. Streamline
6. Which of the following is not a minor loss?
   a. Valve losses
   b. Bend losses
   c. Entrance losses
   d. Pipe friction losses
   e. T-intersection losses

7. Which of the following is not true about the major losses in a pipe?
   a. Friction factors for laminar flow depend on the pipe roughness
   b. The Moody Diagram summarizes friction coefficient data for laminar and turbulent pipe flow
   c. Pipe friction factors are independent of Reynolds number for rough pipes at high Reynolds number
   d. Friction factors for smooth pipes depend on the Reynolds number
   e. Major losses may not be the most important head losses in the pipe network

8. For flow in a concrete pipe (\(\varepsilon = 1.5\) mm) of diameter 0.4 m at a Reynolds number of 200,000 the friction factor \(f\) is closest to
   a. 0.0158
   b. 0.158
   c. 0.0285
   d. 0.285
   e. None of the above

9. For the following flanged tee-connection in a pipe network with the flow direction as shown, the minor loss coefficient \(K_L\) is closest to
   a. 0.2
   b. 0.5
   c. 0.9
   d. 1.0
   e. 2.0

10. Which of the following is true for the total drag on a sphere
    a. The only drag force acting on a sphere is due to skin friction on the sphere surface
    b. The only drag force acting on a sphere is due to a pressure differential across the sphere from the upstream to downstream hemispheres
    c. Dimples on a golf ball always increase the total drag since they increase the roughness
    d. The drag is constant for all Reynolds numbers at a given value of the surface roughness
    e. The drag is a combination of pressure and friction drag that depends on the Reynolds number
Work Out Problems (points as indicated for a total of 60 points)

For the work out problems, please show all your work. Write down all general equations used and intermediate algebraic steps. Failure to include important steps in a solution will result in a lower score. Please do not leave any problem blank: partial credit will be awarded for correct parts of the problem solution. Submit your solution in the space provided or attach additional sheets as necessary.

For problems 11 and 12, consider the following pipe network in a fluid mechanics laboratory. The pipe diameter is 5 cm, and the equivalent roughness is 0.05 mm. All connections are flanged.
11. Determine the net reaction force on the pipe system to the right of the pump for the design flow rate of 0.02 m³/s. Assume there are no head losses.

   a. (10 points) Apply the energy equation between points B and C to determine the pressure at B (remember to ignore head losses!).

   b. (5 points) Draw the appropriate control volume for the momentum equation for the section to the right of the pump.
c. (15 points) Solve for the reaction forces (x and y directions) necessary to hold the pipe network to the right of the pump in place (neglect the weight of the water and the self-weight of the pipe).
12. Evaluate the pipe system at the design flow rate of 0.02 m$^3$/s considering all the major and minor losses when $h = 4$ m by answering the following questions.

   a. (10 points) Calculate the total head loss $h_L$ (minor and major losses) for the entire pipe network when the valve is fully open.
b. (10 points) Apply the energy equation with the head losses from part (a.) to determine the pump size (in kW) necessary to achieve the design flow rate of 0.02 m³/s with the valve fully open. Do not forget to account for the pump efficiency.
c. (5 points) Discuss how the flow rate in the system will change as the valve is slowly closed but the pump continues to run at constant power.

d. (5 points) Does the flow rate at C depend on the depth \( h \) in tank 1? Why or why not?