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Final Exam – Part I: Closed Book (25%)

Particle Technology
CHEN 4838/5838 – Fall 2002

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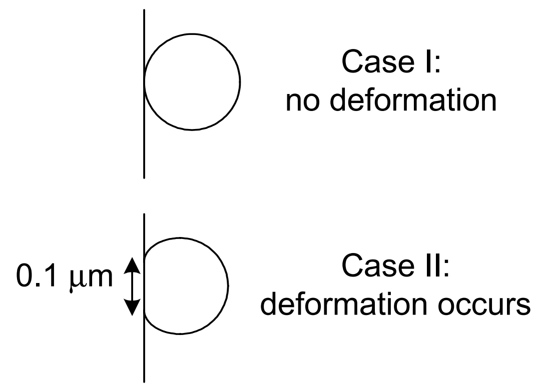
1. *(2 pts.)* Which of the following boundary type(s) are better suited to inelastic systems in sustained motion: standard periodic boundary conditions, Lees-Edwards boundary conditions, stationary walls (i.e. a box), moving studded walls. Why?

2. *(2 pts.)* What are two challenges associated with the scale-up of fluidized beds?

3. *(3 pts.)* Find the time-averaged form of the quantity $\frac{\partial}{\partial x_i}\left(V_i C_A\right)$, which represents the convective transport of species *A*. V_i refers to the i-component of the velocity and C_A refers to the concentration of *A*. Recall the definition of a time-averaged quantity *X* as given below. (The final answer should not contain any integrals.)

$$\overline{X} = \frac{1}{\Delta t}\int_{t}^{t+\Delta t} X \; dt$$

4. *(2 pts.)* As part of homework and class exercise, recall that the collision of a quartz particle with a wall was considered. Specifically, as shown in figure to right, two cases were considered: one in which no particle deformation occurred at contact (Case I), and the other in which signification deformation took place. For particle-wall attraction arising from van der Waals forces, the following values were obtained for V_i^* (i.e., the critical velocity which indicates the boundary between particle stick and bounce).



Case I: V_i^* (10 µm particle) $= 2.9 \times 10^{-3}$ m/s
V_i^* (1000 µm particle) $= 2.9 \times 10^{-5}$ m/s

Case II: V_i^* (10 µm particle) $= 4.65 \times 10^{-2}$ m/s
V_i^* (1000 µm particle) $= 2.9 \times 10^{-5}$ m/s

a.) For both of the above cases, V_i^* for the 1000 µm particle is smaller than that of the 10 µm particle. What is the physical reason for this trend?

b.) Comparing the two cases above, values for V_i^* take on different values for the 10 µm particle, but are identical for the 1000 µm particle. Explain.

5. *(2 pts.)* Suppose that a continuum model for a gas-liquid system (e.g., gas bubbling through a liquid) is being developed. How many momentum balance(s) would be used to describe the system? For each momentum balance(s), what is the specific quantity being conserved?

6. *(1 pts.)* What dimensionless number is an indicator of the relative importance of particle inertia and fluid viscosity effects?

7. *(2 pts.)* Could an eddy-viscosity model be used in conjunction with the time-averaged form of the Navier-Stokes equation to solve for single-phase, steady, laminar flow in a pipe? Is there a more appropriate approach to model such flow? Explain.

8. *(2 pts.)* The drag force around a single sphere at low Re (i.e., Stokes flow) is given by the expression $F_D = 6\pi \mu U_{rel} R$. Is this expression appropriate as-is for use in a discrete-element simulation of a fluidized bed (assuming that the low Re assumption is still valid), or is a modification to the force description needed? Explain.

9. *(3 pts.)* Match the model type with the information that can be gleaned from the model of the fluid-solid system. (Note that the matches do not have to be one-to-one in nature.)

Model type	*Information available from model*
Direct Numerical Simulation (DNS)	Fluid velocity as a function of spatial coordinates
Eulerian/Lagrangian	
Eulerian/Eulerian	Velocity of individual particle as a function of space and time
Macroscopic	

10. *(6 pts.)* True/False

_____ The most appropriate algorithm for the DEM modeling of a densely-packed system, such as particles moving in the interior of a hopper, is an event-driven algorithm.

_____ For mixing operations performed in rotary cylinders, each of the seven flow types (sliding, surging, slumping, rolling, cascading, cataracting, and centrifuging) finds use in a practical application.

_____ A common challenge associated with traditional settling-velocity measurements of continuous size distributions is the lack of a clear interface between zones containing different particle compositions.

_____ When two aerosol particles collide, they typically coagulate due to strong interparticle (cohesive) forces such as van der Waals forces.

_____ Dust explosions are more likely for particles with large specific surface areas.

_____ Bubbling fluidized beds are not characterized by regions of very little mixing (i.e., "dead zones").

Bonus (*1 pt.*): A true/false inspired by Peter Johnson:

_____ Seven flow types can be identified for mixing operations performed in rotary cylinders.

Final Exam – Part II: Open Crib Sheet (75%)

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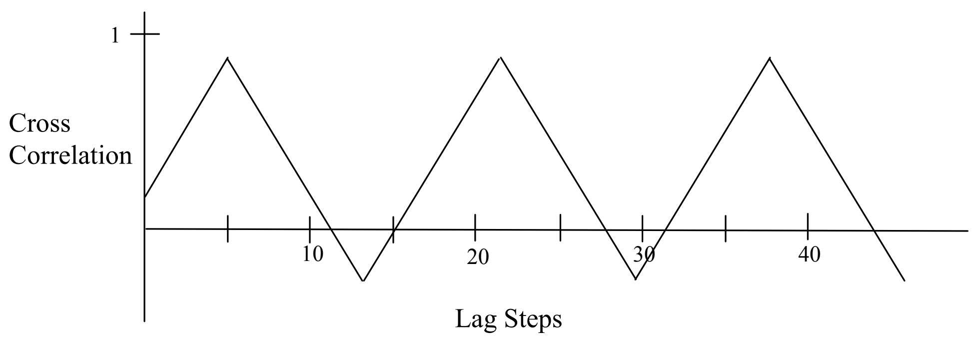
Important Note: The problem statements given below may contain extra information that is not needed for problem solution. Correspondingly, some information needed for problem solution may require values which are not provided in the problem statement, but are available in the textbook or handouts. Clearly state all assumptions used for problem solution.

Problem 1 (15 points)

The diagram shown is the beginning of the cross-correlation for an infinite series of *uniform* bubbles passing *uniformly* over two probes separated by 0.5 in. Lag steps correspond to a 1kHz signal.



a) What type of probe (pressure or optic) would ideally produce this cross correlation? Draw a qualitative representation of the raw signal associated with one of the two probes.
b) How would this cross correlation be qualitatively different if the series of bubbles were not infinite (e.g., only five bubbles passed over the probes)?
c) What is the bubble velocity?
d) What is the bubble pierced length measured by these probes? Under what conditions would this pierced length correspond to the actual bubble diameter?

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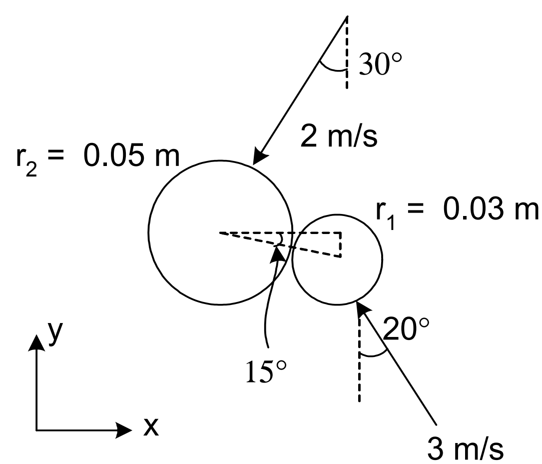
Problem 2 (30 points)

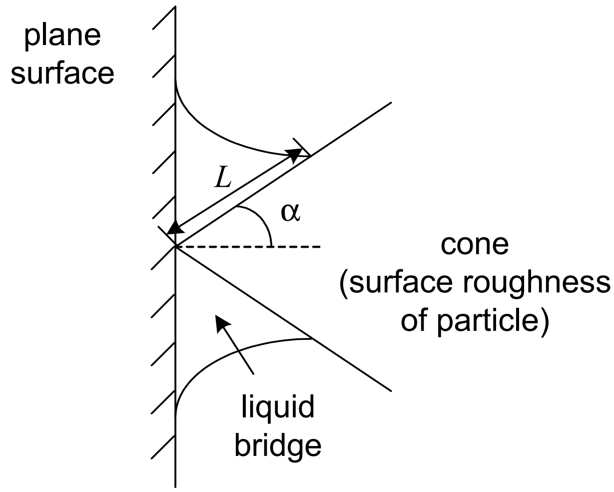
Two spheres of different densities are traveling in a plane and collide, as depicted in figure to right. The densities of particles 1 and 2 are 900 kg/m^3 and 850 kg/m^3, respectively. The coefficient of restitution characterizing the collision is 0.9.

a.) Find the velocities of each particle after the collision occurs.
b.) What is the distance between the particle centers 1 s after the collision?



Problem 3 (30 points)

Typical particles in practical applications are not truly spherical, especially when considering microscopic surface roughness. Oftentimes, such roughness can be approximated by other simplified geometries. For example, consider a rough particle colliding with a motionless, plane surface. Water moisture is present in this system to the extent that pendular liquid bridges will form. For this case, the liquid bridge force can be approximated as that which arises from a liquid bridge forming between a cone (i.e., the microscopic roughness) and a plane, as depicted in figure to right. For such a system, the magnitude of the resulting capillary force (F) is given by



$$F = \pi \gamma L \tan\alpha \left[1 + \cos^2\alpha + \sin\alpha - \cos\alpha\right]$$

where γ refers to the surface tension of the fluid forming the bridge.

The system under consideration is characterized by a particle diameter of 100 μm, particle density of 700 kg/m^3, water surface tension of 0.072 N/m, water density of 1000 kg/m^3, L = 0.5 μm, and α = 25°. Both the particle and wall are made of the same metal material, with a coefficient of restitution equal to 0.92.

a.) What is the magnitude of the cohesive force arising from the liquid bridge?

b.) Is the liquid bridging force greater for the rough particle considered in part (a) or its perfectly smooth, spherical counterpart? Justify with appropriate calculations. Clearly state all assumptions.

c.) Now consider a system in which no moisture is present. What is the maximum *realistic* value of the van der Waals force between a smooth, spherical particle and the wall? At this limit, what is the minimum incoming velocity needed for the particle to bounce from the wall (as opposed to sticking)?

d.) Is the critical velocity (i.e., the velocity which indicates the boundary between particle stick and bounce) for the particle considered in part (a) expected to be larger or smaller than that of part (c)? (Note: Calculations are not necessary for the answer – just explain in words.)