1. (15%) In a turbulent flow the fluid and flow variables (such as velocity and pressure) vary with time. Accordingly, we may express the fluid and flow variables in terms of a mean value and a fluctuating value. According to the definition of the time-averaged variables, please derive the time-averaged NS equation of motion for one-dimensional (in the x direction) turbulent flow of a fluid with constant density and viscosity. Also explain the physical significance of Reynolds stress in the time-averaged equation of motion. [Hint: the Navier-Stokes (NS) equation $\rho \dfrac{Du}{Dt} = -\nabla P + \mu\nabla^2 u + \rho g$] (Note: state the steps and definitions of all variables.)

2. (15%) Comment and discuss briefly the following statements to indicate weather each of these statements below is truth or false.

   A. (3%) Liquids and low-density gases reveal the similar temperature dependence of viscosity; namely, their viscosities increase with increasing temperature.

   B. (3%) For flow at very low speeds and with large viscosity such as occur in lubrication, it is possible to delete the inertial terms Du/Dt, from the Navier-Stokes (u: velocity, t: time, and Du/Dt: substantial time derivative of velocity).

   C. (3%) For turbulent flow of a Newtonian fluid, the eddy viscosity is a constant and strongly depends on the property of the fluid.

   D. (3%) The Newtonian fluid with velocity distributions of $u_x = (-1/5)bx$, $u_y = (-1/5)by$ and $u_z = 5bz$ (b: constant; x, y and z coordinates) is an incompressible fluid.

   E. (3%) Velocity potentials (Φ) are only used to solve 2-dimensional irrotational flow problems; in other words, that means invalid for solving either 1- or 3-dimensional irrotational flow problems.

3. (15%)

   A. (7%) Write down the definitions of Nusselt number and Biot number. What is the difference between Nusselt number and Biot number?

   B. (8%) What dimensionless number(s) influence Nusselt number? Please also write down the definition of the dimensionless number(s).
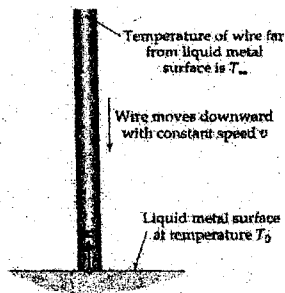
4. (15%)

Fig.　Wire moving into a liquid metal bath.

A wire of constant density ρ moves downward with uniform speed v into a liquid metal bath at temperature T_0. It is desired to find the wire temperature profile $T(z)$. Assume that $T = T_\infty$ at $z = \infty$, and the resistance to radial heat conduction is negligible. Assume further that the wire temperature is $T = T_0$ at $z = 0$ and the wire physical properties $\hat{C}_p$ and k are constant. $\hat{C}_p$ is the wire heat capacity referring to unit mass.

5. (20%) Which statements below are **false** (choose FOUR correct answers)?

   A. The McCabe-Thiele method could only be applied to distillation and gas absorption.

   B. The slope of the stripping line has to be equal to or greater than the slope of the rectifying line in a continuous distillation.

   C. For a continuous fractionating column, the number of stages approaches a minimum when the reflux ratio becomes very great.

   D. For a countercurrent extractor with reflux, a minimum value of the reflux ratio is reached where the number of stages becomes infinite as the reflux ratio is reduced.

   E. Neither crystal growth nor formation of nuclei from the solution can occur in a saturated or unsaturated solution.

   F. The operating temperature in membrane separation processes is determined by balancing the needs for high flux and high selectivity because an increase in temperature usually increases the membrane selectivity and decreases the membrane permeability.

   G. Tie lines connect the equilibrium phases of the binodal curve on an equilateral-triangle diagram in extraction.

   H. Tie lines could slope upward from the extract side to the raffinate side of the equilateral-triangle diagram in extraction.

   I. On the x-y diagram, the McCabe-Thiele construction method can be started at either end of the distillation column.

   J. The definition of the minimum reflux ratio for a distillation column is based on the situation that when either the rectifying line or the stripping line or both lines touch the equilibrium curve on the x-y diagram.

   K. The fixed charges for the distillation column first increase and then decrease with reflux ratio.

   L. The fixed charges on the reboiler and condenser increase steadily with the reflux ratio.

   M. In leaching, the equilibrium line is always straight.

   N. Distillation, extraction, crystallization, evaporation and dialysis are all mass transfer techniques.

   O. The falling-rate period of the drying rate curve may decrease linearly with time or may give plots that are concave upward or concave downward.

   P. The critical moisture content is a property of the material being dried.

   Q. The distribution coefficient is the ratio of the equilibrium concentration of the solute in the extract to that in the raffinate.

   R. The operating line of desorption lies below the equilibrium line as in distillation.

   S. The equilibrium line is always straight in leaching.

   T. The onset of flooding in a distillation column is independent from the density of the vapor phase.

   U. Diffusion of solutes through certain types of polymeric solids is more like diffusion through liquid solutions than any of the other solid-diffusion phenomena.

   V. For crystals with lattices of cubic symmetry, the diffusivity is isotropic.

6. (20%) Gas A diffuses through a stagnant gas film with a thickness of δ to the surface of a nonporous cylindrical catalyst with a length of L and a radius of R where it undergoes the reaction $2A \rightarrow B$ with a reaction rate constant of k_1. Gas B then diffuses from the catalyst surface and is swept away. Neglecting diffusion and reaction on the ends of the particle, derive an equation for the molar flux of A if the reaction is fast (note: state the steps and definitions of all variables.)

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