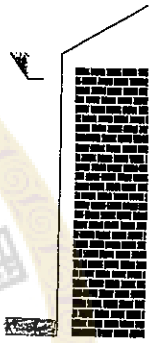
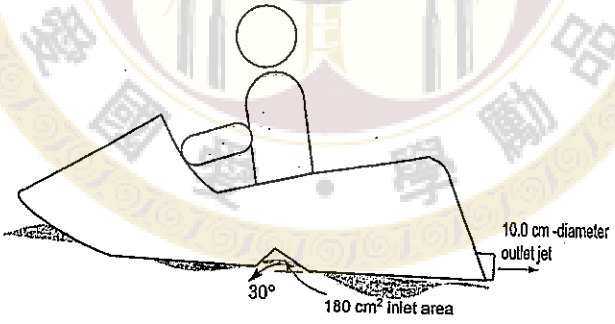
1. The force, F, experienced by an airplane wing depends on the air density, ρ, air viscosity, μ, and the average wind speed speed, V, as well as the chord length, ℓ, and chord span, s, of the wing. Derive the relationship in the dimensionless form. (10%)

2. You are designing the gutter for a miniature house. Assume that the rainfall is laminar and the drainpipe is 2 mm in diameter and 25 cm in length. (a) When the gutter is full, what is the volume flow rate of draining? (10%) (b) The gutter is designed for a sudden rainstorm of up to 6 mm per hour. For this condition, what is the maximum roof area that can successfully drain the water? (5%) (c) What is the Reynolds number. (5%)



3. When you ride jet ski, the water pumps through the vehicle and exists as a high-speed water jet, which will result in a thrust to propel the vehicle. The inlet jet is 30 degree tilted from the water surface and its area is 180 cm^2. The diameter of the outlet jet is 10 cm. Determine what flowrate is needed to produce a 1.5 kN thrust? Assume steady state and the inlet and outlet jets of water are free jets. (20%)



4. Starting with the momentum balance of a particle falling in the viscous fluid by its own weight due to gravity, derive an equation for terminal velocity of the particle. List all nomenclatures used in your derivation with appropriate SI units. (10%) What changes would have to be made if the derived equation is used in designing of a disk bowl centrifuge. (5%)

C_D: drag coefficient, Re: Reynolds number. $C_D=24/Re$

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5. A non-conventional evaporator for short contact time is used to concentrate a fermentation broth. The evaporator consists of a compact shell-and-tube heat exchanger, an expansion valve (pressure reducing valve), a flash chamber for vapor separation, and a condenser to condense water vapor and maintain the pressure.
a. Fermentation broth (c_p=4.2k J/kg℃) is to be heated from 20℃ to 60℃ at a rate of 0.3 kg/s in the compact 1-1shell-and-tube heat exchanger of 0.5m-length and 2cm-diameter thinwalled copper tubes by condensing steam outside at a temperature of 130℃. For an overall heat transfer coefficient of 500 W/m² ℃ determine the rate of heat transfer and number of tubes in the heat exchanger required to achieve it. (10%)
b. Steam heated broth is then flashed to cool down to 15℃ in the flash chamber. What is the evaporation rate in the process? (5%)
c. Show schematically the possible design of the condenser. (5%)

Properties of Saturated Steam and Water

Temperature (℃)	Vapor Pressure (kPa)	Enthalpy Liquid (kJ/kg)	Enthalpy Sat'd Vapor (kJ/kg)
15	1.705	62.99	2528.9
20	2.346	83.95	2538.1
60	19.940	251.13	2609.6
130	270.1	546.31	2720.5

6. In production of whey protein isolate, the charged whey proteins adsorb unto oppositely charged ion-exchange beads. The adsorption properties can be modeled using a nonlinear Langmuir-type adsorption isotherm:

$$q = Q\frac{c/K}{1+c/K}$$

Where q is the concentration of protein adsorbed onto beads (kg/kg), Q is the maximum adsorption capacity of the beads for protein(kg/kg), K is the dissociation equilibrium constant of protein(kg/kg), and c is the bulk liquid concentration of protein(kg/kg).
The double-adsorb technique was suggested by Howell et al. (1990). In this process, w kg of fresh whey with a protein concentration c_o is first contacted with m kg of regenerated beads of a protein concentration q_o=0. Fresh whey and ion-exchange beads are equilibrated in a tank. The tank is then drained and the partially spend whey (c_1) is stored temporarily. The tank now contains spent beads (q_1) which are washed, eluted and regenerated. The temporarily stored whey is add back to the tank, to contact with regenerated beads (q_o=0). At equilibrium spent whey with a protein concentration c_2 is discarded and ion-exchange beads (q_2) are regenerated for the next cycle.
a. Use material balance equations to model the process, assuming the bulk weight of whey and ion-exchange beads are constant in the operation. (5%)
b. Because of nonlinear nature of the model graphic method is often used to solve those equations. Show schematically the method on a q vs. c diagram. (10%)

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