國立清華大學 104 學年度碩士班考試入學試題

系所班組別：化學工程學系碩士班

考試科目（代碼）：輸送現象及單元操作(0901)

請在【答案卡】作答

Problem 1 (20 Points)

Multiple choice: (Pick only one answer for each problem.)

1. What is the SI unit of mass diffusivity?
   (A) Kg/s, (B) m^2/s, (C) mole/s, (D) Kmole/s.
2. What is the SI unit of Schmidt number?
   (A) 1/m, (B) 1/Kg, (C) 1/Kmole, (D) none of the above.
3. For the following mixtures, (a) Ar-O_2 at 1 atm and 273 K, (b) Ar-O_2 at 1 atm and 373 K, (c) Ar-O_2 at 0.1 atm and 373 K, and (d) H_2-O_2 at 0.1 atm and 373 K, place them in the order of increasing mass diffusivity.
   (A) (b)(a)(d)(c), (B) (b)(a)(c)(d), (C) (a)(b)(c)(d), (D) (a)(b)(d)(c).
4. For gas mixtures, the Schmidt numbers are with an order of magnitude of:
   (A) <<1, (B) ~1, (C) >>1, (D) none of the above.
5. Consider a spherical particle A of radius R dissolving in a stagnant liquid B. Once dissolved, A and B react to form C with a first order reaction (reaction rate constant k_1). The solubility of A in B, C_{A0}, is small and the system can be approximated as a dilute binary system. The diffusivity of A in B is D_{AB}. The system can be treated as in a pseudo-steady state. Let b^2 denote (k_1R^2/D_{AB}). What is the concentration distribution of A?
   (A) $\frac{C_A}{C_{A0}}=\frac{r}{R}e^{-b(r/R-1)}$, (B) $\frac{C_A}{C_{A0}}=\frac{R}{r}e^{b(r/R-1)}$, (C) $\frac{C_A}{C_{A0}}=\frac{R}{r}e^{-b(r/R-1)}$,
   (D) $\frac{C_A}{C_{A0}}=\frac{r}{R}e^{b(r/R-1)}$.
6. Continued from the above problem, what is dR/dt? (M_A=molecular weight of A, ρ_A=density of A)
   (A) $\frac{dR}{dt}=-\frac{M_AD_{AB}C_{A0}(1+b)}{R\rho_A}$, (B) $\frac{dR}{dt}=-\frac{M_AD_{AB}C_{A0}}{R\rho_A(1+b)}$, (C) $\frac{dR}{dt}=\frac{M_AD_{AB}C_{A0}}{R\rho_A(1+b)}$,
   (D) $\frac{dR}{dt}=\frac{M_AD_{AB}C_{A0}(1+b)}{R\rho_A}$.

7. In a vertical tube, a liquid B moves slowly upward through a slightly soluble porous plug of A. Then A slowly disappears by a first order reaction (with a reaction rate constant k_1) after it has dissolved. Let z be the coordinate upward from the plug. Assume that the velocity profile is approximately flat across the tube with an average velocity of v_0. Let C_{A0} be the solubility of A in B and D_{AB} the mass diffusivity. Assume dilute binary systems and steady state. What is the concentration distribution of A? Let a denote $-\dfrac{v_0}{2D_{AB}}\left[-\sqrt{1+4k_1D_{AB}/v_0^2}-1\right]$ and b denote $-\dfrac{v_0}{2D_{AB}}\left[\sqrt{1+4k_1D_{AB}/v_0^2}-1\right]$.
(A) $\dfrac{C_A}{C_{A0}}=e^{az}$, (B) $\dfrac{C_A}{C_{A0}}=e^{bz}$, (C) $\dfrac{C_A}{C_{A0}}=e^{b/z}$, (D) $\dfrac{C_A}{C_{A0}}=e^{-a/z}$.

8. Continued from the above problem, what will C_A tend to if v_0 becomes very large? (A) C_{A0}, (B) 0, (C) infinity, (D) none of the above.

9. The equation of continuity of A in a dilute binary solution can be written as

$$\frac{\partial C_A}{\partial t}+\underline{v}\cdot\underline{\nabla}C_A=D_{AB}\nabla^2C_A+R_A,$$

Here, $\underline{v}$ is the mass average velocity and R_A is the molar reaction rate of A. For the situation of stationary liquid and no reactions, what will the above equation be reduced to?

(A) $\underline{v}\cdot\underline{\nabla}C_A=D_{AB}\nabla^2C_A+R_A$, (B) $\dfrac{\partial C_A}{\partial t}+\underline{v}\cdot\underline{\nabla}C_A=0$,
(C) $\dfrac{\partial C_A}{\partial t}=D_{AB}\nabla^2C_A+R_A$, (D) $\dfrac{\partial C_A}{\partial t}=D_{AB}\nabla^2C_A$.

10. The equation of continuity of A in a binary gas mixture can be written as

$$\frac{\partial C_A}{\partial t}+\underline{v}^*\cdot\underline{\nabla}C_A=D_{AB}\nabla^2C_A+(C_BR_A-C_AR_B)/C,$$

Here, $\underline{v}^*$ is the molar average velocity and R_B is the molar reaction rate of B and C is the total molar concentration. For the situation of equi-molar counter-diffusion in gases with no reactions, what will the above equation be reduced to?

(A) $\dfrac{\partial C_A}{\partial t}=D_{AB}\nabla^2C_A+(C_BR_A-C_AR_B)/C$; (B) $\dfrac{\partial C_A}{\partial t}+\underline{v}^*\cdot\underline{\nabla}C_A=D_{AB}\nabla^2C_A$;
(C) $\dfrac{\partial C_A}{\partial t}=D_{AB}\nabla^2C_A$; (D) $\underline{v}^*\cdot\underline{\nabla}C_A=D_{AB}\nabla^2C_A+(C_BR_A-C_AR_B)/C$.

以下各題請在【答案卷】作答

Problem 2 (20 Points)

A uniform liquid film coated on a polymer substrate as shown in the figure is placed inside an oven for drying test. Properties of the liquid film and the polymer substrate are as follows:

(1) Liquid film

(a) Composition

(1) SiO_2 particles (20%)

(2) polyvinyl alcohol (PVA) (10%)

(3) water (70%)

(b) Properties: heat capacity / thermal conductivity / density

(1) SiO_2: C_{ps}/ Ks/ ρ_s

(2) PVA:C_{pv}/ K_{PV}/ ρ_v

(3) Water: C_{pw}/ K_w/ ρ_w

(4) Latent heat of water: λ_w

(2) Polymer substrate

(1) Heat capacity: C_{pp}

(2) Thermal conductivity: K_{pp}

(3) Density: ρ_{pp}

The initial dimensions of the liquid film and the substrate are given in the figure. Initially hot air of temperature T_{A1} is blowing on the film which temperature is around room temperature T_R, after a few minutes, the air temperature is switched to T_{A2}, because it is believed that diffusion of water molecules is a critical step for drying and T_{A2} is necessary for fast drying.

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Please answer the following questions:

(I) True and False. (10%)

(a) The film is dried mainly by free convection.

(b) When the film is totally dried, the weight of the dry film (polymer substrate not included) is around 20% of the initial weight.

(c) For defect-free drying, T_{A1} should be lower than T_{A2}, T_{A1} should be less than 100°C

(d) It is better to dry the film from both top and bottom together.

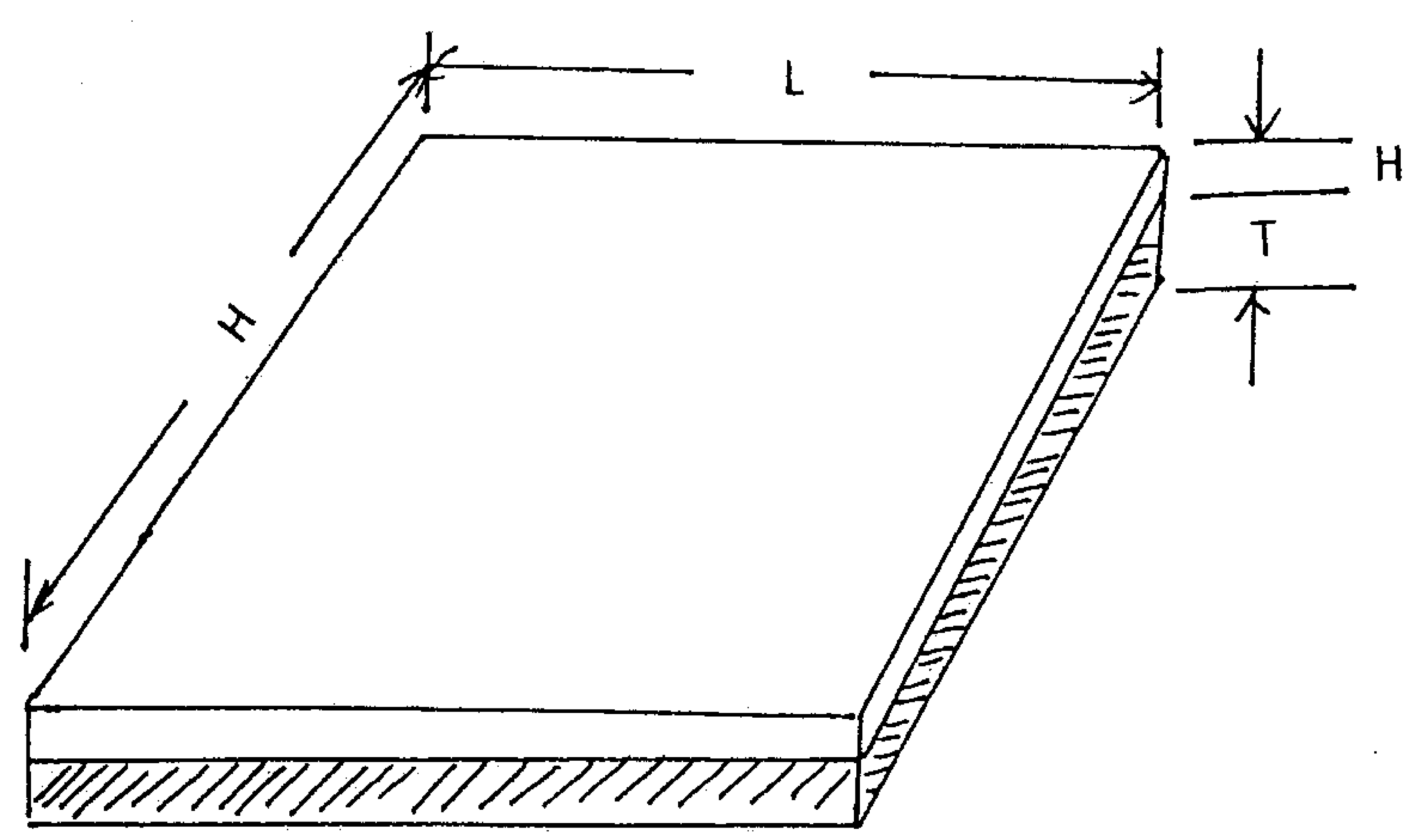
(e) Polymer substrate is usually a very good thermal conducting medium.

(II) (f)Please estimate the total amount of heat required to dry the liquid film. (4%)

(III)

(g) Please write down the 1-D time dependent heat transfer equation for the liquid film and the polymer substrate separately. (4%)

(h) Write down the proper initial and boundary conditions for the 1-D heat transfer equation for the diffusion-controlled regime of the film. i.e., phase change at the liquid surface will not reduce the film thickness significantly. (2%)



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Problem 3 (10 Points)

在一 3/8 in. schedule 40 之管線， 其管內側熱傳係數 h_i 為 1500 W/m^2-C，管外側熱傳係數 h_o 為 2500 W/m^2-C，金屬管之導熱係數為 57 W/m-C。假設管線無壁垢，管長為 2 m。

(a) 管外為 120℃之飽和蒸汽，管內之進出口處之水溫各為 20℃及 95℃。求每一公尺長之管線之熱傳速率(以 W 為單位表示) (5 %)

(b) 同樣之管線操作狀況下，若管內壁垢係數及管外壁垢係數別為 1900 W/m^2-C 及 3400 W/m^2-C，當進口之水溫仍為 20℃時，出口水溫為何？(5 %)

鐵管之規格

A.5-1 Dimensions of Standard Steel Pipe

Nominal Pipe Size (in.)	Outside Diameter in.	Outside Diameter mm	Schedule Number	Wall Thickness in.	Wall Thickness mm	Inside Diameter in.	Inside Diameter mm	Inside Cross-Sectional Area ft^2	Inside Cross-Sectional Area $m^2 \times 10^4$
1/8	0.405	10.29	40	0.068	1.73	0.269	6.83	0.00040	0.3664
			80	0.095	2.41	0.215	5.46	0.00025	0.2341
1/4	0.540	13.72	40	0.088	2.24	0.364	9.25	0.00072	0.6720
			80	0.119	3.02	0.302	7.67	0.00050	0.4620
3/8	0.675	17.15	40	0.091	2.31	0.493	12.52	0.00133	1.231
			80	0.126	3.20	0.423	10.74	0.00098	0.9059
1/2	0.840	21.34	40	0.109	2.77	0.622	15.80	0.00211	1.961
			80	0.147	3.73	0.546	13.87	0.00163	1.511
3/4	1.050	26.67	40	0.113	2.87	0.824	20.93	0.00371	3.441
			80	0.154	3.91	0.742	18.85	0.00300	2.791
1	1.315	33.40	40	0.133	3.38	1.049	26.64	0.00600	5.574
			80	0.179	4.45	0.957	24.31	0.00499	4.641
1 1/4	1.660	42.16	40	0.140	3.56	1.380	35.05	0.01040	9.648
			80	0.191	4.85	1.278	32.46	0.00891	8.275
1 1/2	1.900	48.26	40	0.145	3.68	1.610	40.89	0.01414	13.13
			80	0.200	5.08	1.500	38.10	0.01225	11.40
2	2.375	60.33	40	0.154	3.91	2.067	52.50	0.02330	21.65
			80	0.218	5.54	1.939	49.25	0.02050	19.05
2 1/2	2.875	73.03	40	0.203	5.16	2.469	62.71	0.03322	30.89
			80	0.276	7.01	2.323	59.00	0.02942	27.30
3	3.500	88.90	40	0.216	5.49	3.068	77.92	0.05130	47.69
			80	0.300	7.62	2.900	73.66	0.04587	42.61
3 1/2	4.000	101.6	40	0.226	5.74	3.548	90.12	0.06870	63.79
			80	0.318	8.08	3.364	85.45	0.06170	57.35

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Problem 4 (10 Points)

一蛋白質 (濃度 1.0 mg/ml) 水溶液以吸附管柱進行純化。其突破曲線以下表之數據表示：

x-axis 時間 (hr)	0	3	4	5	6
y-axis 濃度(mg/ml)	0	0	0.33	0.67	1.0

突破濃度訂為 0.05 mg/ml,

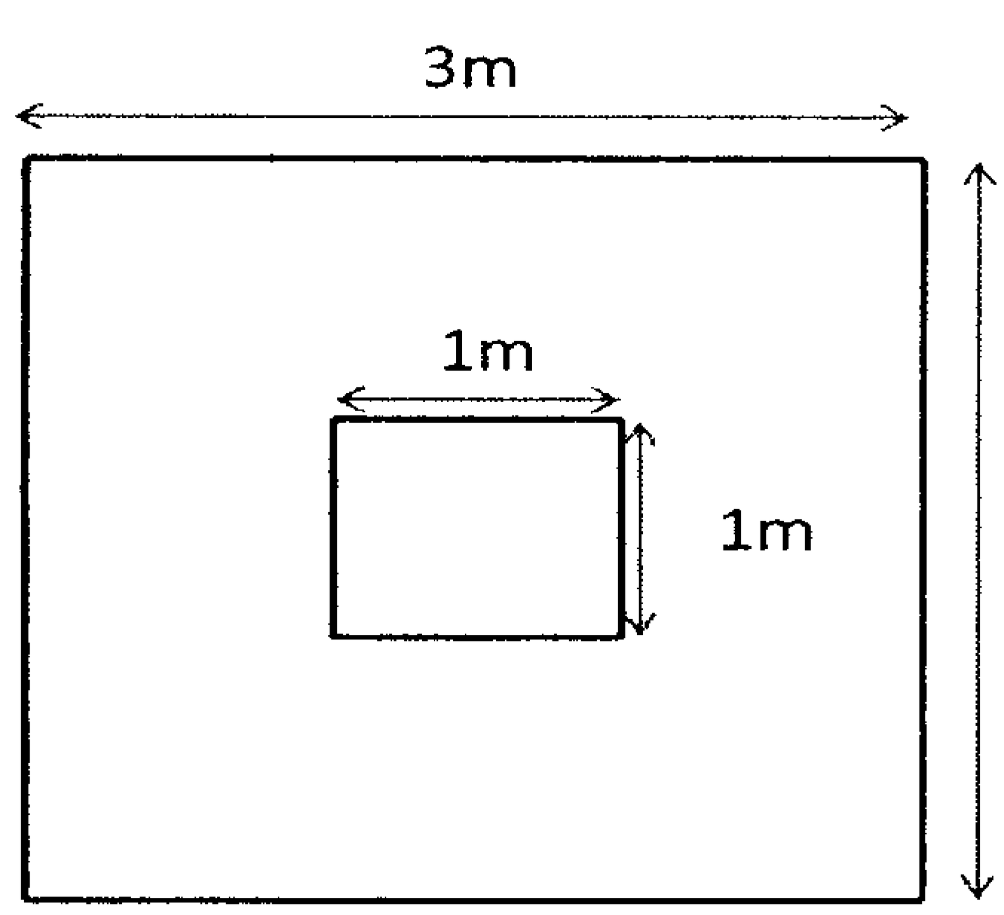
(a) 請問到達突破點時，管柱之使用效率為何? (5 %)

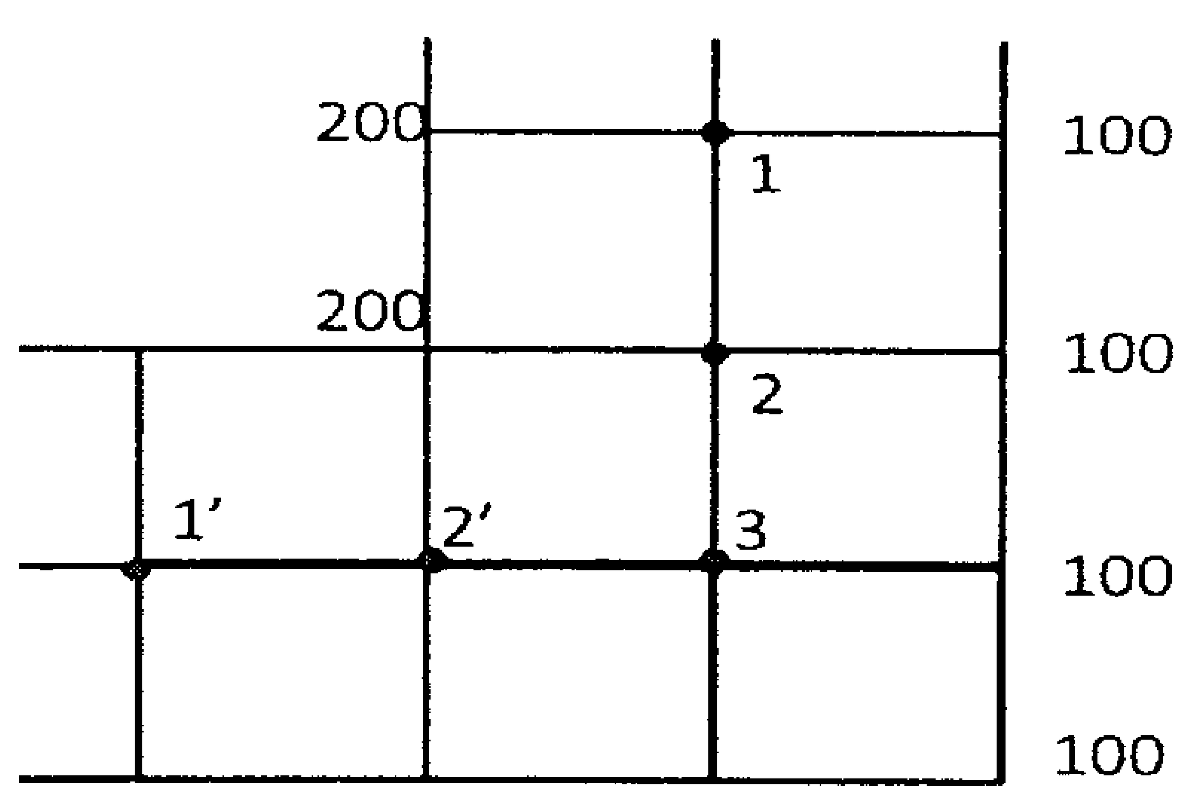
(b) 如果我們換用同樣型式，但有兩倍長的管柱作前述之純化工作，此一管柱到達突破點時，其使用效率為何? (5 %)

Problem 5 (20 Points)

(a) (10%)A square pan with its bottom surface maintained at 350 K is exposed to water vapor at 1 atm pressure and 373 K. The pan has a lip all around so the condensate that forms can not flow away. How deep will the condensate film be after 10 min have elapsed at this condition?

(b) (10%) A hollow square duct of the configuration shown (left) has its surfaces maintained at 200 K and 100 K, respectively. Determine the steady-state heat transfer rate between the hot and cold surface of this duct. The wall material has a thermal conductivity of 1.21 W/m·K. We may take advantage of the eightfold symmetry of this figure to lay out the simple square grid shown below (right).





Problem 6 (10 Points)

A stream of water of diameter d = 0.1 m flows steadily from a tank of diameter D = 1.0 m. What is the flow rate, Q (m^3/s), needed from the inflow pipe if the water depth inside the tank remains constant at h = 2.0 m?

*Assume steady, inviscid, incompressible flow
$g = 9.81\ m/s^2$

Problem 7 (10 Points)

A wide moving belt passes through a container of viscous liquid. The belt moves vertically upward with a constant velocity V_0. Because of viscous forces, the belt picks up a film of fluid of thickness h. Gravity tends to make the fluid drain down the belt. Find the velocity distribution of the fluid film as it is dragged up by the moving belt.

* The liquid is Newtonian fluid with constant density and viscosity
* Assume the flow is laminar, steady, and fully developed
* Assume shearing stress is zero on the film surface (that is, the drag of the air on the film is negligible)

(接下頁 EQUATION)

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NEWTON'S LAW OF VISCOSITY

$$[\boldsymbol{\tau} = -\mu(\nabla \mathbf{v} + (\nabla \mathbf{v})^\dagger) + (\tfrac{2}{3}\mu - \kappa)(\nabla \cdot \mathbf{v})\boldsymbol{\delta}]$$

Cartesian coordinates (x, y, z):

$$\tau_{xx} = -\mu\left[2\frac{\partial v_x}{\partial x}\right] + (\tfrac{2}{3}\mu - \kappa)(\nabla \cdot \mathbf{v}) \quad \text{(B.1-1)}^a$$

$$\tau_{yy} = -\mu\left[2\frac{\partial v_y}{\partial y}\right] + (\tfrac{2}{3}\mu - \kappa)(\nabla \cdot \mathbf{v}) \quad \text{(B.1-2)}^a$$

$$\tau_{zz} = -\mu\left[2\frac{\partial v_z}{\partial z}\right] + (\tfrac{2}{3}\mu - \kappa)(\nabla \cdot \mathbf{v}) \quad \text{(B.1-3)}^a$$

$$\tau_{xy} = \tau_{yx} = -\mu\left[\frac{\partial v_y}{\partial x} + \frac{\partial v_x}{\partial y}\right] \quad \text{(B.1-4)}$$

$$\tau_{yz} = \tau_{zy} = -\mu\left[\frac{\partial v_z}{\partial y} + \frac{\partial v_y}{\partial z}\right] \quad \text{(B.1-5)}$$

$$\tau_{zx} = \tau_{xz} = -\mu\left[\frac{\partial v_x}{\partial z} + \frac{\partial v_z}{\partial x}\right] \quad \text{(B.1-6)}$$

in which

$$(\nabla \cdot \mathbf{v}) = \frac{\partial v_x}{\partial x} + \frac{\partial v_y}{\partial y} + \frac{\partial v_z}{\partial z} \quad \text{(B.1-7)}$$

[a] When the fluid is assumed to have constant density, the term containing $(\nabla \cdot \mathbf{v})$ may be omitted. For monatomic gases at low density, the dilatational viscosity κ is zero.

THE EQUATION OF CONTINUITY[a]

$$[\partial\rho/\partial t + (\nabla \cdot \rho\mathbf{v}) = 0]$$

Cartesian coordinates (x, y, z):

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x}(\rho v_x) + \frac{\partial}{\partial y}(\rho v_y) + \frac{\partial}{\partial z}(\rho v_z) = 0 \quad \text{(B.4-1)}$$

Cylindrical coordinates (r, θ, z):

$$\frac{\partial \rho}{\partial t} + \frac{1}{r}\frac{\partial}{\partial r}(\rho r v_r) + \frac{1}{r}\frac{\partial}{\partial \theta}(\rho v_\theta) + \frac{\partial}{\partial z}(\rho v_z) = 0 \quad \text{(B.4-2)}$$

Spherical coordinates (r, θ, φ):

$$\frac{\partial \rho}{\partial t} + \frac{1}{r^2}\frac{\partial}{\partial r}(\rho r^2 v_r) + \frac{1}{r\sin\theta}\frac{\partial}{\partial \theta}(\rho v_\theta \sin\theta) + \frac{1}{r\sin\theta}\frac{\partial}{\partial \phi}(\rho v_\phi) = 0 \quad \text{(B.4-3)}$$

[a] When the fluid is assumed to have constant mass density ρ, the equation simplifies to $(\nabla \cdot \mathbf{v}) = 0$.

THE EQUATION OF MOTION IN TERMS OF τ

$$[\rho D\mathbf{v}/Dt = -\nabla p - [\nabla \cdot \boldsymbol{\tau}] + \rho\mathbf{g}]$$

Cartesian coordinates (x, y, z):[a]

$$\rho\left(\frac{\partial v_x}{\partial t} + v_x\frac{\partial v_x}{\partial x} + v_y\frac{\partial v_x}{\partial y} + v_z\frac{\partial v_x}{\partial z}\right) = -\frac{\partial p}{\partial x} - \left[\frac{\partial}{\partial x}\tau_{xx} + \frac{\partial}{\partial y}\tau_{yx} + \frac{\partial}{\partial z}\tau_{zx}\right] + \rho g_x \quad \text{(B.5-1)}$$

$$\rho\left(\frac{\partial v_y}{\partial t} + v_x\frac{\partial v_y}{\partial x} + v_y\frac{\partial v_y}{\partial y} + v_z\frac{\partial v_y}{\partial z}\right) = -\frac{\partial p}{\partial y} - \left[\frac{\partial}{\partial x}\tau_{xy} + \frac{\partial}{\partial y}\tau_{yy} + \frac{\partial}{\partial z}\tau_{zy}\right] + \rho g_y \quad \text{(B.5-2)}$$

$$\rho\left(\frac{\partial v_z}{\partial t} + v_x\frac{\partial v_z}{\partial x} + v_y\frac{\partial v_z}{\partial y} + v_z\frac{\partial v_z}{\partial z}\right) = -\frac{\partial p}{\partial z} - \left[\frac{\partial}{\partial x}\tau_{xz} + \frac{\partial}{\partial y}\tau_{yz} + \frac{\partial}{\partial z}\tau_{zz}\right] + \rho g_z \quad \text{(B.5-3)}$$

[a] These equations have been written without making the assumption that $\boldsymbol{\tau}$ is symmetric. This means, for example, that when the usual assumption is made that the stress tensor is symmetric, τ_{xy} and τ_{yx} may be interchanged.