

研究所・高普考叢書

單元操作用象 解題技巧
單輪送現

編著者 劉 弘 揚

曉園出版社
世界圖書出版公司

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单元操作输送现象解题技巧

刘弘扬 编

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序 言

單操輸送學爲化工之基礎，亦爲研究所、高考、化工技師檢覈及升技術學院之必考科目，所以想在各種考試中順利過關，單操輸送是必讀的重要科目。

坊間有關單操輸送之書籍均著重於理論之陳述，無法對解題有深一層之解說，尤其理論陳述繁雜，往往讀完後似懂非懂，遑論解題？筆者有鑒於此，特集數年來補習班教學經驗與資料，編成此書以針對各項考試之快速正確解題。

本書以歷年各項考試爲準編寫而成，編列歷年各項考試中有出現之題型，並闡述解題技巧，使讀者在讀完本書後，對解題必有十足的信心，本書附有各校歷年研究所入學試題及解答，書後亦列出歷年高考試題以供參考。

筆者不佞，雖竭智窮慮，猶恐掛一漏萬，盼先進賢達不吝指正，俾作修正，以期更臻完美。

劉弘揚 謹識

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Part(I) Transport phenomena

(A) The Simulation Problems and Solutions for Momentum transfer

The Problem-Solving Approach :

(→) Extracting the N-S Eq method

- (1) Carefully read the problem statement
- (2) Choose a coordination system (rectangular, Cylindrical and Spherical)
- (3) Sketch system diagram
- (4) Extract the describing N-S Diff Eqs
- (5) Set up BC & IC
- (6) Solve the Eqs, Subject to BC & IC
- (7) Analyse the Results

(→) Shell-balance method Analysis

- (1) Choose a Shell size
- (2) Force Balance
- (3) Shear force related to velocity gradient
- (4) Velocity distribution Solved (B.C Known)
- (5) Average or Max. velocity
- (6) Drag force

Example 1.

Steady state of laminar flow for Newton's Incompressible fluids between two parallel plates find

1 Velocity profile ?

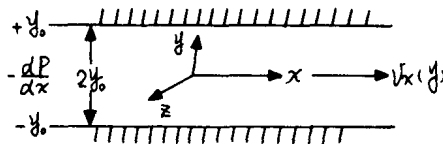
2 Pressure drop per unit length of the conduit $\frac{dp}{dx} = ?$

3 $V_{x, \max} = ?$

4 $\langle V_{x, \text{ave}} \rangle = ?$

5 $Q = ?$

4] (By Simplifying Navier-Stokes eq



from eq of continuity $\nabla \cdot \vec{v} = 0$

$$\frac{\partial V_x}{\partial x} + \frac{\partial V_y}{\partial y} + \frac{\partial V_z}{\partial z} = 0 \Rightarrow \frac{\partial V_x}{\partial x} = 0 \Rightarrow \frac{\partial^2 V_x}{\partial x^2} = 0$$

$$\rho \frac{D\vec{v}}{Dt} = -\nabla P + \rho \vec{g} + \mu \nabla^2 \vec{v}$$

$$\nabla = \frac{\partial}{\partial x} \vec{i} + \frac{\partial}{\partial y} \vec{j} + \frac{\partial}{\partial z} \vec{k}, \vec{v} = V_x \vec{i} + V_y \vec{j} + V_z \vec{k}$$

from Eq of motion x-component

$$\frac{\rho}{g_c} \left(\frac{\partial V_x}{\partial t} + V_x \frac{\partial V_x}{\partial x} + V_y \frac{\partial V_x}{\partial y} + V_z \frac{\partial V_x}{\partial z} \right) = -\frac{\partial P}{\partial x}$$

$$\mu \left(\frac{\partial^2 V_x}{\partial x^2} + \frac{\partial^2 V_x}{\partial y^2} + \frac{\partial^2 V_x}{\partial z^2} \right) + \frac{\rho}{g_c} g_x$$

$$\Rightarrow \frac{\partial P}{\partial x} = \mu \frac{\partial^2 V_x}{\partial y^2} \Rightarrow \frac{dP}{dx} = \mu \frac{d^2 V_x}{dy^2} = \text{const}$$

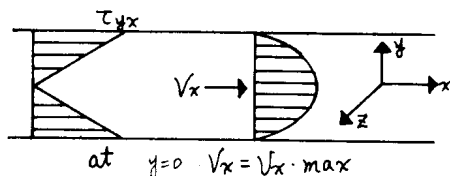
$$\text{B.C } \begin{cases} (1) y = \pm y_0, & V_x = 0 \\ (2) y = 0 & V_x = \text{finite} \Rightarrow \frac{dV_x}{dy} = 0 \end{cases}$$

$$\frac{dv_x}{dy} = \frac{1}{\mu} \frac{dP}{dx} y + C_1 \quad \text{with B.C(2)} \Rightarrow C_1 = 0$$

$$\frac{dv_x}{dy} = \frac{1}{\mu} \frac{dP}{dx} y \Rightarrow \text{integrate} \Rightarrow V_x = \frac{1}{\mu} \frac{dP}{dx} \cdot \frac{1}{2} y^2 + C_2$$

$$\text{using B.C(1)} \Rightarrow C_2 = -\frac{1}{\mu} \frac{dP}{dx} \cdot \frac{1}{2} \cdot y_0^2$$

$$1 \Rightarrow V_x = \frac{1}{\mu} \frac{dP}{dx} \cdot \frac{1}{2} (y^2 - y_0^2) \leftarrow V_x \text{ 對 } y \text{ 爲一拋物線}$$



$$2 \Rightarrow V_{x,max} = \frac{1}{-2\mu} \frac{dP}{dx} y_0^2$$

$$\Rightarrow V_x = \frac{1}{-2\mu} \frac{dP}{dx} y_0^2 \left[1 - \left(\frac{y}{y_0} \right)^2 \right]$$

$$= V_{x,max} \left[1 - \left(\frac{y}{y_0} \right)^2 \right]$$

$$3 < V_{x,ave} > = \frac{\int_{-y_0}^{y_0} \int_0^w V_x dy dz}{\int_{-y_0}^{y_0} \int_0^w dy dz} = \frac{Q}{A}$$

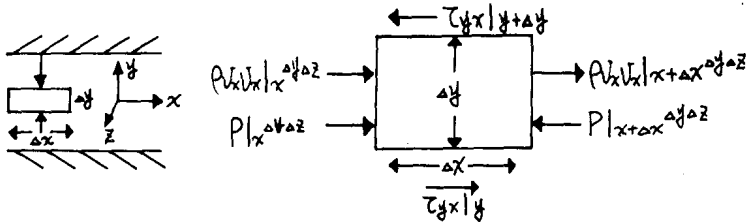
$$4. Q = \int dQ = \int V_x dA = \int_{-y_0}^{y_0} V_{x,max} \left[1 - \left(\frac{y}{y_0} \right)^2 \right] dy \quad (\text{per unit width})$$

$$= \frac{1}{-2\mu} \frac{dP}{dx} \int_{-y_0}^{y_0} (y_0^2 - y^2) dy = \frac{1}{-2\mu} \frac{dP}{dx} \frac{4}{3} y_0^3$$

$$= \frac{-2}{3\mu} \frac{dP}{dx} y_0^3 = \frac{4}{3} V_{x,max} y_0$$

$$< V_{x,ave} > = \frac{Q}{A} = \frac{\frac{4}{3} V_{x,max} y_0}{2 y_0} = \frac{2}{3} V_{x,max}$$

(二) Byshell Balance :



Momentum Balance : $I_n - \text{Out} + \sum F^2 = \text{Accum}$

($\because$ fully developed)

$$\begin{aligned} & \rho(Vv|_x - v v|_{x+\Delta x}) \Delta y \Delta z \leftarrow \text{convective term} \\ & + (\tau_{yx}|_y - \tau_{yx}|_{y+\Delta y}) \Delta x \Delta z \leftarrow \text{shear force term} \\ & + (P|_x - P|_{x+\Delta x}) \Delta y \Delta z \leftarrow \text{pressure force term} \\ & = 0 \quad (\because \text{S.S}) \end{aligned}$$

$$\Rightarrow (\tau_{yx}|_y - \tau_{yx}|_{y+\Delta y}) \Delta x \Delta z + (P|_x - P|_{x+\Delta x}) \Delta y \Delta z = 0$$

$$\div \Delta x \Delta y \Delta z$$

$$\Rightarrow \frac{\tau_{yx}|_y - \tau_{yx}|_{y+\Delta y}}{\Delta y} + \frac{P|_x - P|_{x+\Delta x}}{\Delta x} = 0$$

take limit $\Delta x \rightarrow 0 \quad \Delta y \rightarrow 0$

$$\Rightarrow \frac{d\tau_{yx}}{dy} + \frac{dP}{dx} = 0$$

Beacuse it. is a Newton's fluid

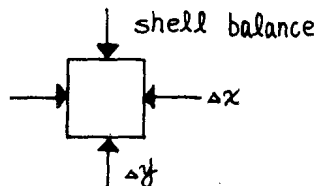
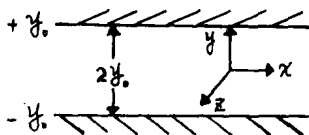
$$\tau_{yx} = -\mu \frac{dV_x}{dy}$$

$$\Rightarrow \frac{d\tau_{yx}}{dy} = -\mu \frac{d^2 V_x}{dy^2} = -\frac{dP}{dx}$$

$$\Rightarrow \frac{dP}{dx} = \mu \frac{d^2 V_x}{dy^2}$$

just the same the result By N-S Eq

Detail discussion:



$$\frac{1}{\mu} \frac{d^2 V_x}{dy^2} = \frac{dP}{dx}$$

$$\Rightarrow V_x = \frac{1}{\mu} \frac{dP}{dx} \frac{y^2}{2} + C_1 y + C_2 \rightarrow (A)$$

B · C discussion

(1) If both plates are stationary

$$V_x = (V_x)_{max} \left[1 - \left(\frac{y}{y_0} \right)^2 \right]$$

(2) Asufficient force is applied to the upper plate to maintain a velocity V_0

$$(1) y = -y_0, \quad V_x = 0$$

B · C {

$$(2) y = y_0, \quad V_x = V_0$$

Substituting B · C into eq(A), We get C_1, C_2

$$0 = \frac{1}{2\mu} \frac{dP}{dx} y_0^2 + C_1(-y_0) + C_2$$

$$V_0 = \frac{1}{2\mu} \frac{dP}{dx} y_0^2 + C_1(y_0) + C_2$$

$$\text{聯立解: } C_1 = \frac{V_0}{2y_0}, \quad C_2 = \frac{V_0}{2} - \frac{1}{2\mu} \frac{dP}{dx} y_0^2$$

$$V_x = \frac{1}{2\mu} \frac{dP}{dx} y^2 + \frac{V_0}{2y_0} y + \frac{V_0}{2} - \frac{1}{2\mu} \frac{dP}{dx} y_0^2$$

$$= \frac{1}{2\mu} \left(-\frac{dP}{dx} \right) (y_0^2 - y^2) + \frac{V_0}{2} \left(\frac{y}{y_0} + 1 \right)$$

(3) If the Lower plate is set in motion $V = V_0^*$

$$(1) y = -y_0 \quad V_x = V_0^*$$

B · C {

$$(2) y = y_0 \quad V_x = 0$$

代入 eq. (A) 聯立解 C_1, C_2

$$C_1 = \frac{-V_0^*}{2y_0}$$

$$C_2 = \frac{V_0^*}{2} - \frac{1}{2\mu} \frac{dP}{dx} y_0^2$$

$$\Rightarrow V_x = \frac{1}{2\mu} \frac{dP}{dx} y^2 - \frac{V_0^*}{2y_0} y + \frac{V_0^*}{2} - \frac{1}{2\mu} \frac{dP}{dx} y_0^2$$

$$= \frac{1}{2\mu} \left(-\frac{dP}{dx} \right) (y_0^2 - y^2) + \frac{V_0^*}{2} \left(1 - \frac{y}{y_0} \right)$$

(4) If Both plate are moving

upper plate = V_0

Lower plate = V_0^*

a. if the direction is the same.

$$B \cdot C \begin{cases} (1) y = -y_0 & V_x = V_0^* \\ (2) y = y_0 & V_x = V_0 \end{cases}$$

代入 eq (A) 聯立解

$$C_1 = \frac{V_0 - V_0^*}{2y_0}$$

$$C_2 = \frac{V_0^* + V_0}{2} - \frac{1}{2\mu} \frac{dP}{dx} y_0^2$$

$$\Rightarrow V_x = \frac{1}{2\mu} \left(-\frac{dP}{dx} \right) (y_0^2 - y^2) + \frac{y}{2y_0} (V_0 + V_0^*) + \frac{V_0 + V_0^*}{2}$$

b. if the direction is reversed

$$B \cdot C \begin{cases} (1) y = -y_0 & V_x = -V_0^* \\ (2) y = y_0 & V_x = V_0 \end{cases}$$

$$C_1 = \frac{1}{2y_0} (V_0 + V_0^*)$$

$$C_2 = \frac{V_0 - V_0^*}{2} - \frac{1}{2\mu} \frac{dP}{dx} y_0^2$$

$$\Rightarrow V_x = \frac{1}{2\mu} \left(-\frac{dP}{dx} \right) (y_0^2 - y^2) + \frac{y}{y_0} (V_0 + V_0^*) + \frac{V_0 - V_0^*}{2}$$

(5) (Power Law) applied for Non-Newtonian fluid between parallel plate

$$B \cdot C \begin{cases} (1) y = \pm y_0, V_x = 0 \\ (2) y = 0, \tau_{yx} = 0 \end{cases}$$

$$\frac{d\tau_{yx}}{dy} = - \left(\frac{dP}{dx} \right) \Rightarrow \tau_{yx} = \left(- \frac{dP}{dx} \right) y + C_1$$

$$B \cdot C (2) \Rightarrow C_1 = 0 \Rightarrow \tau_{yx} = \left(- \frac{dP}{dx} \right) y$$

in Power Law fluid

$$\tau_{yx} = m \left(- \frac{dV_x}{dy} \right)^n = \left(- \frac{dP}{dx} \right) y$$

$$\Rightarrow - \frac{dV_x}{dy} = \left[\frac{1}{m} \left(- \frac{dP}{dx} \right) y \right]^{1/n}$$

integral

$$\Rightarrow -V_x = \int \left[\frac{1}{m} \left(- \frac{dP}{dx} \right) \right]^{1/n} y^{1/n} dy$$

$$= \left[\frac{1}{m} \left(- \frac{dP}{dx} \right) \right]^{1/n} \int y^{1/n} dy$$

$$= \left[\frac{1}{m} \left(- \frac{dP}{dx} \right) \right]^{1/n} \left[\frac{y^{1/n + 1}}{1 + \frac{1}{n}} + C_2 \right]$$

$$= \left[\frac{1}{m} \left(- \frac{dP}{dx} \right) \right]^{1/n} \left(\frac{n}{n+1} y^{1/n + 1} + C_2 \right)$$

$$B \cdot C (1) \Rightarrow C_2 = - \frac{n}{n+1} y_0^{1/n + 1}$$

$$\Rightarrow V_x = \left[\frac{1}{m} \left(- \frac{dP}{dx} \right) \right]^{1/n} \underbrace{\left(\frac{n}{n+1} \right) y_0^{n/n+1}}_{(V_x)_{max} \text{ at } y=0} \left[1 - \left(\frac{y}{y_0} \right)^{n/n+1} \right]$$

$$\Rightarrow V_x = (V_x)_{max} \left[1 - \left(\frac{y}{y_0} \right)^{n/n+1} \right]$$

$$\langle V_x \rangle = \frac{\int_0^w \int_{-y_0}^{y_0} V_x dy dz}{\int_0^w \int_{-y_0}^{y_0} dy dz} = \frac{2w \int_0^{y_0} \left[V_{x,max} \left(1 - \left(\frac{y}{y_0} \right)^{n/n+1} \right) dy \right]}{2y_0 \cdot w}$$

$$= (V_x)_{max} \int_0^{y_0} \left[1 - \left(\frac{y}{y_0} \right)^{n/n+1} \right] d \left(\frac{y}{y_0} \right)$$