MASS AND VOLUME FLOW RATES

The t of mass flowing through a cross section per unit time is called the *mass flow rate* and is denote $\dot{m}$

$$d\dot{m} = \rho V_n dA$$

V_n = The velocity component to *dA*

The mass flow through the entire cross-sectional area of the pipe

$$\dot{m} = \int_A \rho V_n dA \quad (kg/s)$$

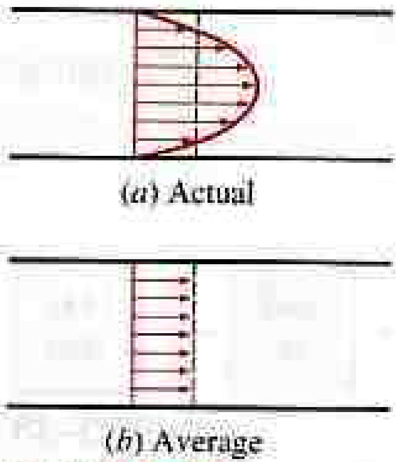


FIGURE 3–40
Actual and mean velocity profiles for flow in a pipe (the mass flow rate is the same for both cases).

MASS AND VOLUME FLOW RATES

$$\dot{m} = \rho V_m A \quad (kg/s)$$

ρ=density of fluid , kg/m³ (=1/v)
V_n = mean fluid velocity normal to A, m/s
A = cross-sectional area normal to flow direction,m²

The volume of the fluid flowing through a cross section per unit time is called the Volume flow rate $\dot{V}$

$$\dot{V} = \int_A V_n dA = V_m A \quad (m^3/s)$$

$$\dot{m} = \rho \dot{V} = \frac{\dot{V}}{v}$$

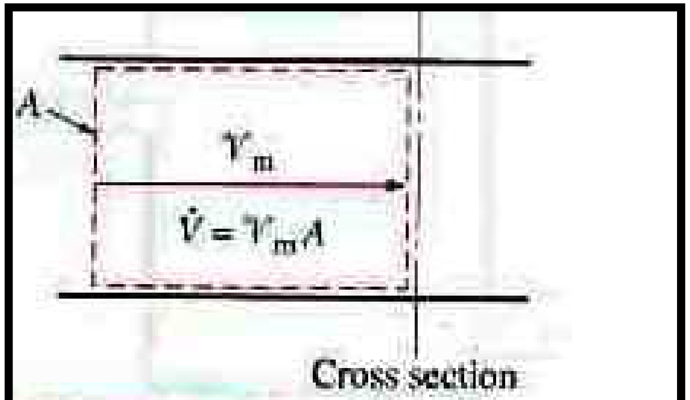


FIGURE 3–41
The volume flow rate is the volume of fluid flowing through a cross section per unit time.

The first law of thermodynamics

กฎข้อที่หนึ่งของเทอร์โมไดนามิกส์ **The first law of thermodynamics** ในระบบปิดใด ๆก็ตาม ถ้าระบบนั้นมีการทำงานครบวัฏจักร **ผลรวมทางพีชคณิตของงานจะมีค่าเท่ากับผลรวมทางพีชคณิตของความร้อน** ดังสมการ

$$\boxed{\sum dW = \sum dQ}$$

CONSERVATION OF MASS PRINCIPLE

มวลที่ถ่ายเทหรือรับจากระบบในช่วงเกิดกระบวนการจากสภาวะที่1 ไปสภาวะที่2

$$\begin{pmatrix}\text{Total mass} \\ \text{entering the} \\ \text{system}\end{pmatrix} - \begin{pmatrix}\text{Total mass} \\ \text{leaving the} \\ \text{system}\end{pmatrix} = \begin{pmatrix}\text{Net chang} \\ \text{in mass} \\ \text{within the} \\ \text{system}\end{pmatrix}$$

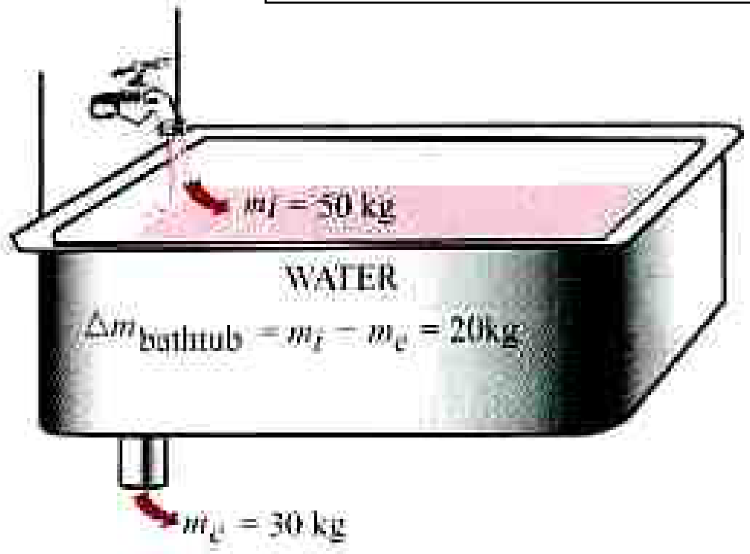


FIGURE 3–42
Conservation of mass principle for an ordinary bathtub.

$$m_{in} - m_{out} = \Delta m_{system} \quad \text{(kg)}$$

$$\Delta m_{system} = m_{final} - m_{initial}$$

$$\dot{m}_{in} = \dot{m}_{out} - dm_{system} / dt \quad \text{(kg/s)}$$

CONSERVATION OF MASS PRINCIPLE

Mass balance for control volume

$$\sum m_i - \sum m_e = (m_2 - m_1)_{system}$$

$$\sum \dot{m}_i - \sum \dot{m}_e = dm_{system} / dt$$

$$\sum \int_{Ai} (\rho V_n dA)_i - \sum \int_{Ae} (\rho V_n d A)_e = \frac{d}{dt} \int_V (\rho dV)_{CV}$$

เรียกสมการต่อเนื่อง (Continuity equation)

Mass Balance for Steady-Flow Processes

$$\begin{pmatrix} \text{Total mass} \\ \text{entering } CV \\ \textit{per unit time} \end{pmatrix} = \begin{pmatrix} \text{Total mass} \\ \text{leaving CV} \\ \text{per unit time} \end{pmatrix}$$

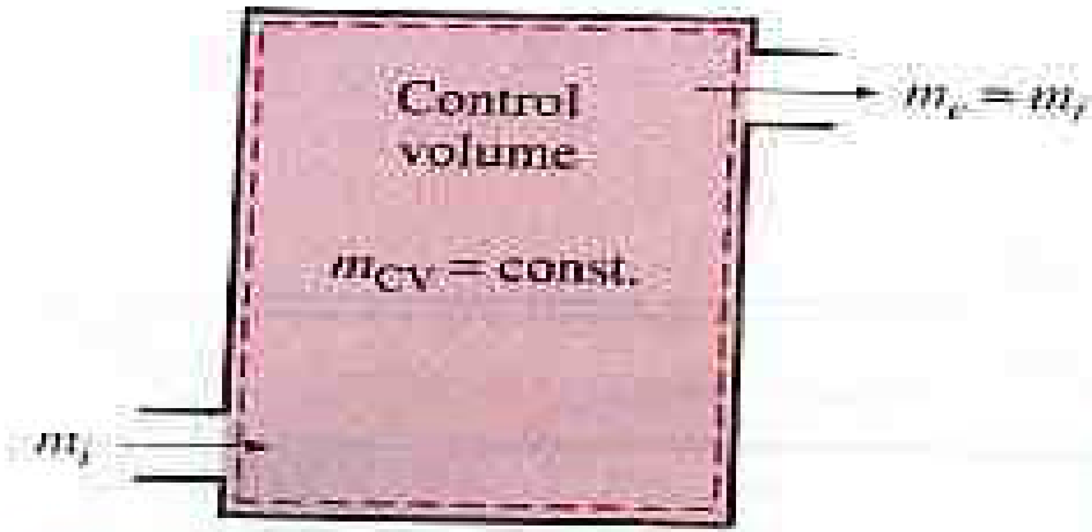


FIGURE 3–43

During a steady-flow process, the amount of mass entering a control volume equals the amount of mass leaving.

$$\sum \dot{m}_i = \sum \dot{m}_r$$

Mass Balance for Steady-Flow Processes

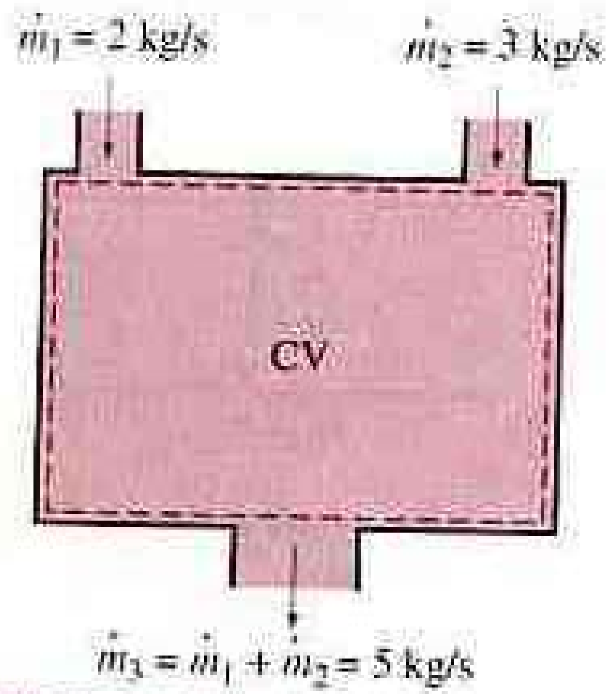


FIGURE 3–44

Conservation of mass principle for a two-inlet–one-exit steady-flow system.

Steady Flow (single stream):

$$\dot{m}_1 = \dot{m}_2 \quad \rightarrow \quad \rho_1 V_1 A_1 = \rho_2 V_2 A_2$$

Special Case: Incompressible Flow (ρ = constant)

Steady Incompressible Flow:

$$\sum \dot{V}_i = \sum \dot{V}_e$$

Steady Incompressible Flow:

(single stream):

$$\dot{V}_1 = \dot{V}_2 \rightarrow V_1 A_1 = V_2 A_2$$

EXAMPLE 3-12 Water Flow through a Garden Hose Nozzle A garden hose attached with a nozzle is used to fill a 10-gallon bucket. The inner diameter of the hose is 2 cm, and it reduces to 0.8 cm at the nozzle exit(Fig.3-46). If it takes 50s to fill the bucket with water. Determine (a) the volume and mass flow rates of water through the hose, (b) the mean velocity of water at the nozzle exit.

$$\dot{V} = \frac{V}{\Delta t} = \frac{10\,gal}{50\,s}\left(\frac{3.7854\,L}{1\,gal}\right) = 0.757\,L/s$$

$$\dot{m} = \rho\dot{V} = (1\,kg/L)(0.757\,L/s) = 0.757\,kg/s$$

$$A_e = \pi r_e^2 = \pi(0.4cm)^2 = 0.5027\,cm^2 = 0.5027\times10^{-4}\,m^2$$

$$V_e = \frac{\dot{V}}{A_e} = \frac{0.757\,L/s}{0.5027\times10^{-4}\,m^2}\left(\frac{1m^3}{1000\,L}\right) = 15.1m/s$$

FIGURE 3–46
Schematic for Example 3–12.

FLOW WORK AND THE ENERGY OF A FLOWING FLUID

Force applied on the fluid element

$$F = PA$$

Flow work

$$W_{flow} = FL = PAL = PV \quad (kJ)$$

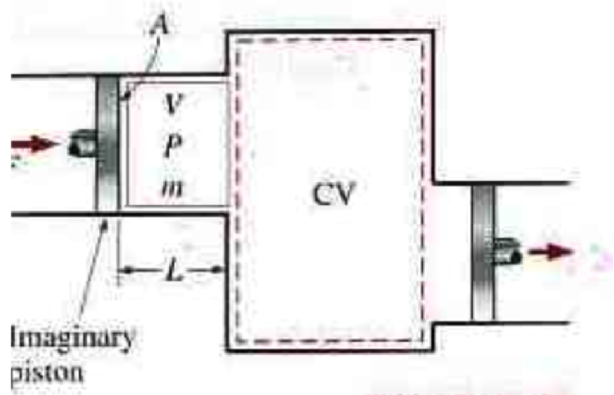


FIGURE 3–48
Schematic for flow work.

Flow work per unitmass

$$w_{flow} = PV \quad (kJ/kg)$$

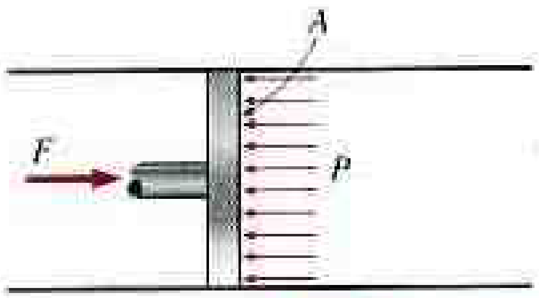
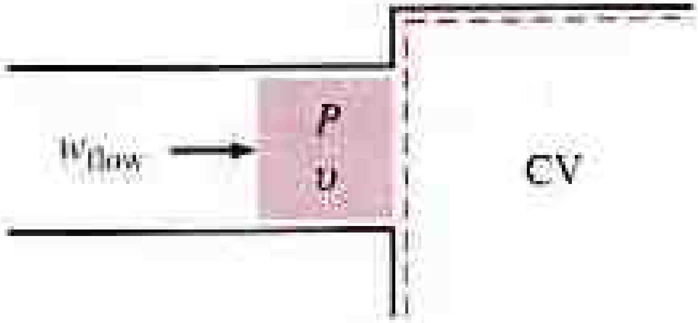
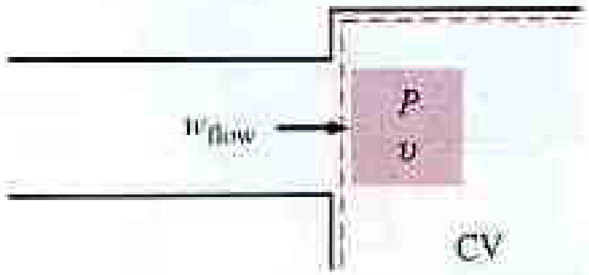


FIGURE 3–49
n the absence of acceleration, the force applied on a fluid by a piston is equal to the force applied on the piston by the fluid.

FLOW WORK AND THE ENERGY OF A FLOWING FLUID



(a) Before entering



(b) After entering

FIGURE 3–50

Flow work is the energy needed to push a fluid into or out of a control volume, and it is equal to Pv.

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Total Energy of a flowing Fluid

Total energy of a simple compressible system

$$e = u + ke + pe = u + \frac{V^2}{2} + gz \quad (kJ/kg)$$

Total energy of a flowing fluid on a unit-mass basic

$$\theta = Pv + e = Pv + (u + ke + pe)$$

$$\theta = h + ke + pe = h + \frac{V^2}{2} + gz, \qquad (kJ/kg)$$

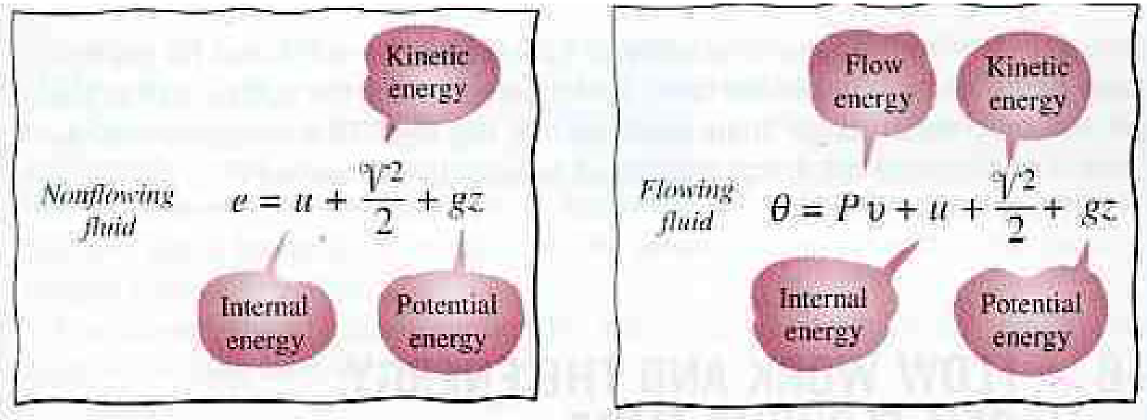


FIGURE 3–51
The total energy consists of three parts for a nonflowing fluid and four parts for a flowing fluid.

Energy Transport by Mass

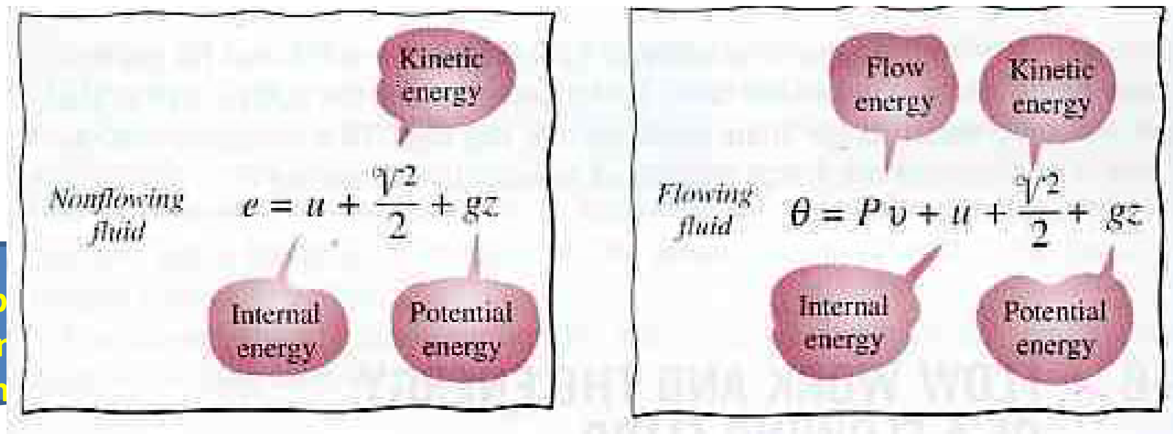
$$E_{mass} = m\theta = m\left(h + \frac{V^2}{2} + gZ\right) \quad (kJ)$$

$$E_{mass} = \dot{m}\theta = \dot{m}\left(h + \frac{V^2}{2} + gZ\right) \quad (kW)$$

$$E_{in,mass} = \int_{mi} \theta_i \delta m_i = \int_{mi} \left(h_i + \frac{V_i^2}{2} + gz_i\right)\delta m_i$$

FIGURE 3–51

The total energy consists of three parts for a nonflowing fluid and four parts for a flowing fluid.



EXAMPLE 3-14 **Steam is leaving a 4-L pressure cooker whose operating pressure is 150 kPa (Fig. 3-53). It is observed that the amount of liquid in the cooker has decreased by 0.6 L in 40 minutes after the steady operating conditions are established, and the cross-sectional area of the exit opening is mm^2 . Determine (a) the mass flow rate of the steam and the exit velocity, (b) The total and flow energies of the steam per unit mass, and © the rate at which energy is leaving is the cooker by steam.**

$$m = \frac{\Delta V_{liquid}}{v_f} = \frac{0.6\text{L}}{0.001053\text{m}^3/\text{kg}}\left(\frac{1\text{m}^3}{1000\text{L}}\right) = 0.570\text{kg}$$

$$\dot{m} = \frac{m}{\Delta t} = \frac{0.570\text{kg}}{40\text{min}} = 0.0142\text{kg/min} = 2.37\times10^{-4}\ \text{kg/s}$$

$$V = \frac{\dot{m}}{\rho_s A_c} = \frac{\dot{m} v_g}{A_c} = \frac{(2.37\times10^{-4}\,kg/s)(1.1593\,m^3 kg)}{8\times10^{-6}\,m^2} = 34.3\,m/s$$

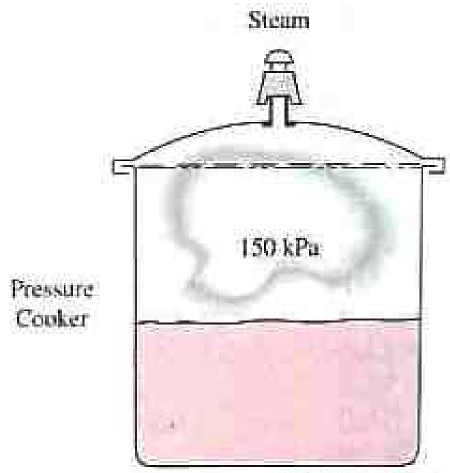


FIGURE 3–53
Schematic for Example 3–14.

EXAMPLE 3-14

(b) Noting that *h=u+Pv* and that the kinetic and potential energies

$$e_{flow} = Pv = h - u = 2693.6 - 2519.7 = 173.9 \quad \text{(kJ/kg)}$$

$$\theta = h + ke + pe \cong h = 2693.6 \quad \text{(kJ/kg)}$$

$$ke = V^2/2 = (34.3 m/s)^2/2 = 588 m^2/s^2 = 0.588 kJ/kg$$

(c) Rate at which energy is leaving the cooker

$$\dot{E}_{mass} = \dot{m}\theta = (2.37 \times 10^{-4} kg/s)(2693.6 kJ/kg) = 0.638 \text{ kW}$$

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PROBLEMS

3-21 During an expansion process, the pressure of agas changes from 103 kPa to 689 kPa according to the relation P=aV+b, where a = 1230 kPa/m^3 and b is a constant. If the initial volume of the gas is 0.198 m^3 ,calaulate the work done during the process. (186.9 kJ)

3-95 Air at 4.18 kg/m^3 enters a nozzle that has an inlet-to-exit area ratio of 2:1 with a velocity of 120 m/s and leaves with a velocity of 380 m/s . Determine the density of air at the exit. (2.64 kg/m^3)