

University of Anbar

Engineering Thermodynamics II

Lecture Note #05: Flow Work and The Energy of a Flowing Fluid



Objective of Lecture Note

- **Introduce the Flow Work and The Energy of a Flowing Fluid.**



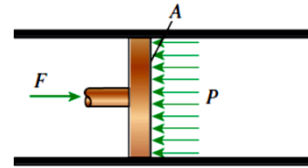
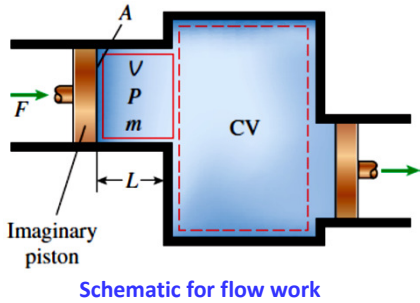
Flow Work and The Energy of a Flowing Fluid

Flow work, or flow energy: The work (or energy) required to push the mass into or out of the control volume. This work is necessary for maintaining a continuous flow through a control volume.

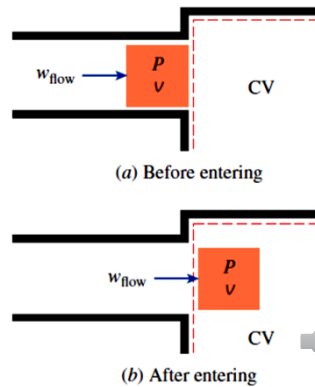
$$F = PA$$

$$W_{\text{flow}} = FL = PAL = P\Delta V \quad (\text{kJ})$$

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



In 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.



Total Energy of a Flowing Fluid

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

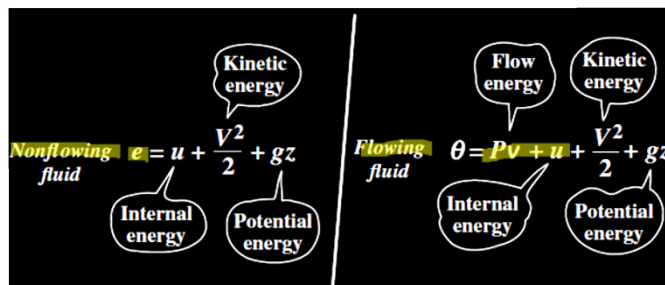
$$\theta = Pv + e = Pv + (u + ke + pe)$$

$$h = u + Pv$$

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

Total Energy of a Flowing Fluid

The flow energy is automatically taken care of by enthalpy. In fact, this is the main reason for defining the property enthalpy.



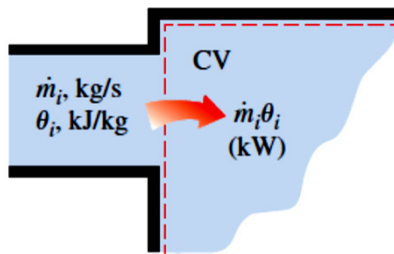
The total energy consists of three parts for a non-flowing fluid and four parts for a flowing fluid.

Energy Transport by Mass

$$e = \frac{E}{m} \rightarrow E = me$$

Amount of energy transport: $E_{\text{mass}} = m\theta = m\left(h + \frac{V^2}{2} + gz\right)$ (kJ) (5-28)

Rate of energy transport: $\dot{E}_{\text{mass}} = \dot{m}\theta = \dot{m}\left(h + \frac{V^2}{2} + gz\right)$ (kW) (5-29)



When the kinetic and potential energies of a fluid stream are negligible

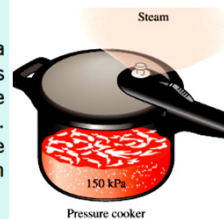
$$E_{\text{mass}} = mh \quad \dot{E}_{\text{mass}} = \dot{m}h$$

The product $\dot{m}_i \theta_i$ is the energy transported into control volume by mass per unit time.



EXAMPLE 5-3 Energy Transport by Mass

Steam is leaving a 4-L pressure cooker whose operating pressure is 150 kPa (Fig. 5-17). It is observed that the amount of liquid in the cooker has decreased by 0.6 L in 40 min after the steady operating conditions are established, and the cross-sectional area of the exit opening is 8 mm². 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 (c) the rate at which energy leaves the cooker by steam.



SOLUTION Steam leaves a pressure cooker at a specified pressure. The velocity, flow rate, the total and flow energies, and the rate of energy transfer by mass are to be determined.

Assumptions 1 The flow is steady, and the initial start-up period is disregarded. 2 The kinetic and potential energies are negligible, and thus they are not considered. 3 Saturation conditions exist within the cooker at all times so that steam leaves the cooker as a saturated vapor at the cooker pressure.

Properties The properties of saturated liquid water and water vapor at 150 kPa are $v_f = 0.001053$ m³/kg, $v_g = 1.1594$ m³/kg, $u_g = 2519.2$ kJ/kg, and $h_g = 2693.1$ kJ/kg (Table A-5).

Analysis (a) Saturation conditions exist in a pressure cooker at all times after the steady operating conditions are established. Therefore, the liquid has the properties of saturated liquid and the exiting steam has the properties of saturated vapor at the operating pressure. The amount of liquid that has evaporated, the mass flow rate of the exiting steam, and the exit velocity are



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

$$\dot{m} = \frac{m}{\Delta t} = \frac{0.570 \text{ kg}}{40 \text{ min}} = 0.0142 \text{ kg/min} = 2.37 \times 10^{-4} \text{ kg/s}$$

$$V = \frac{\dot{m}}{\rho_g A_c} = \frac{\dot{m} \nu_g}{A_c} = \frac{(2.37 \times 10^{-4} \text{ kg/s})(1.1594 \text{ m}^3/\text{kg})}{8 \times 10^{-6} \text{ m}^2} = 34.3 \text{ m/s}$$

(b) Noting that $h = u + Pv$ and that the kinetic and potential energies are disregarded, the flow and total energies of the exiting steam are

$$e_{\text{flow}} = Pv = h - u = 2693.1 - 2519.2 = 173.9 \text{ kJ/kg}$$

$$\theta = h + ke + pe \cong h = 2693.1 \text{ kJ/kg}$$

Note that the kinetic energy in this case is $ke = V^2/2 = (34.3 \text{ m/s})^2/2 = 588 \text{ m}^2/\text{s}^2 = 0.588 \text{ kJ/kg}$, which is small compared to enthalpy.

(c) The rate at which energy is leaving the cooker by mass is simply the product of the mass flow rate and the total energy of the exiting steam per unit mass,

$$\dot{E}_{\text{mass}} = \dot{m}\theta = (2.37 \times 10^{-4} \text{ kg/s})(2693.1 \text{ kJ/kg}) = 0.638 \text{ kJ/s} = 0.638 \text{ kW}$$

