Lecture 6

Energy analysis of unsteady-flow processes

Processes which involve changes (of mass and energy) within the control volume with time are called **unsteady-flow**, or **transient-flow processes.**

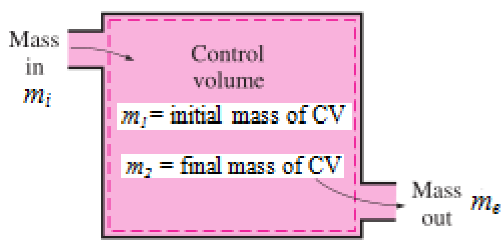
Examples of unsteady flow processes are the charging of rigid vessels from supply lines, discharging a fluid from a pressurized vessel, inflating tyres or balloons etc. Unsteady flow processes may involve moving boundaries and thus boundary work as in the case of inflating balloons.

Unlike steady-flow processes, unsteady-flow processes start and end over some finite time period instead of continuing indefinitely. Therefore in the case of unsteady flow, we deal with changes that occur over some time interval Δt instead of with the rate of changes (changes per unit time).

Mass Balance

$m_i - m_e = (m_1 - m_2)_{CV}$

where i = inlet, e = exit, 1 = initial state, and 2 = final state of the control volume.



Energy Balance

$$\textit{Energy balance:} \qquad \underbrace{E_{in} - E_{out}}_{\substack{\text{Net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{system}}_{\substack{\text{Change in internal, kinetic,}\\ \text{potential, etc., energies}}} \qquad (\text{kJ})$$

The only change in the energy balance equation when comparing with the steady flow energy equation is the right hand side of the equation i.e. ΔE of the system. (also $m_i \neq m_e$)

$\Delta E_{system} = (m_2e_2 - m_1e_1)_{CV}$ where e = u + ke + pe is the energy of the nonflowing fluid within the control volume per unit mass (change in energy between initial and final states)

For a stationary system e = u, i.e. ke and pe will be equal to zero.

The energy balance equation can be written as

$$\left(Q_{in} + W_{in} + \sum_{in} m\theta\right) - \left(Q_{out} + W_{out} + \sum_{out} m\theta\right) = (m_2e_2 - m_1e_1)_{system}$$

where θ = h + ke + pe is the energy of a fluid stream at any inlet or exit per unit mass and

e = u + ke + pe is the energy of the nonflowing fluid within the control volume per unit mass

For single-stream devices and stationary CV

$$Q - W = m_e\left(h_e + \frac{{V_e}^2}{2} + gz_e\right) - m_i\left(h_i + \frac{{V_i}^2}{2} + gz_i\right) + (m_2u_2 - m_1u_1)_{CV}$$

Where $Q = Q_{in} - Q_{out}$, $W = W_{out} - W_{in}$, i represents inlet and e represents exit (outlet), 1 represents the initial state of CV and 2 represents the final state of CV

(Note that for steady flow energy equation 1 and 2 represented inlet and exit respectively but here i and e represents inlet and exit)

Example

A tiny hole develops in the wall of a rigid tank whose volume is 0.75 m^3, and air from the surroundings at 1 bar, 25^0C leaks in. Eventually, the pressure in the tank reaches 1 bar. The process occurs slowly enough that heat transfer between the tank and the surroundings keeps the temperature of the air inside the tank constant at 25^0C. Determine the amount of heat transfer, in kJ, if initially the tank (a) is evacuated. (b) contains air at 0.7 bar, 25^0C.