Thermodynamics I

Chapter 4

The First Law of Thermodynamics

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The First Law of Thermodynamics

- Also called the ***conservation of energy principle***.

Energy can be neither created nor destroyed; it can only change forms.

Energy Balance

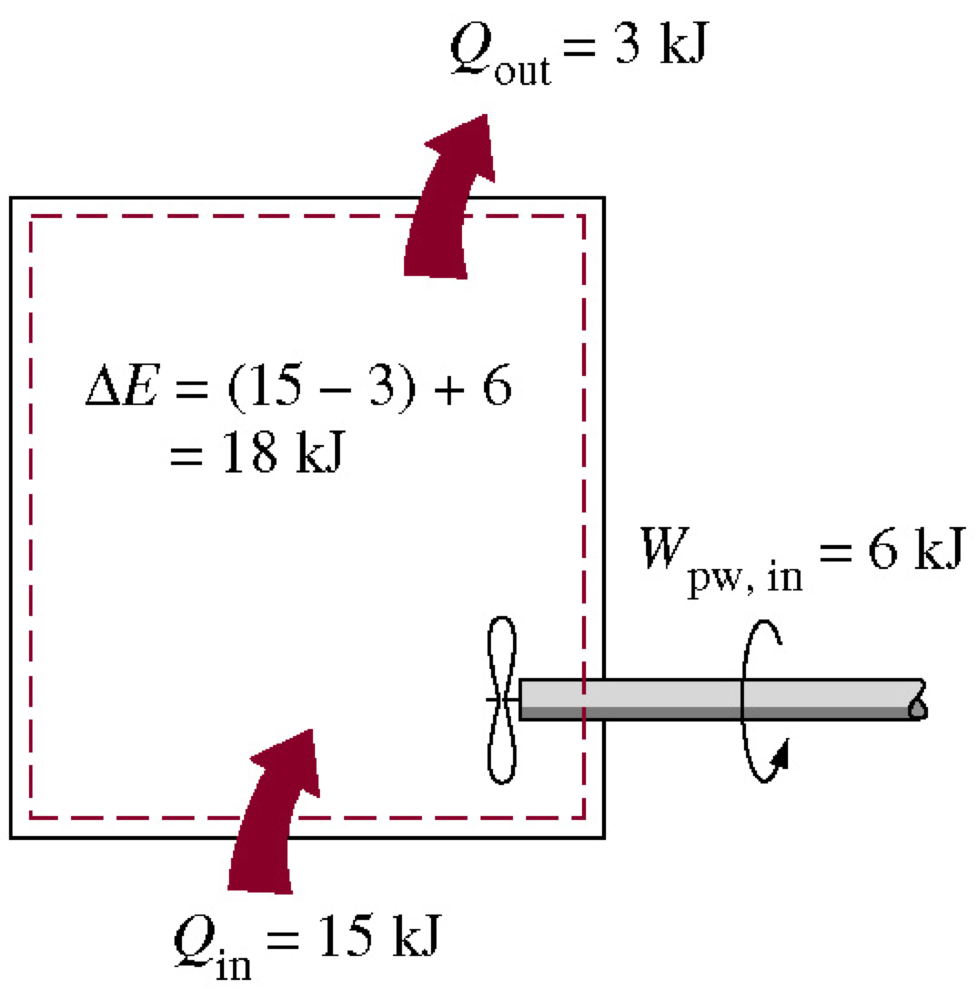
- The net change (increase or decrease) in the total energy of the system during a process is equal to the difference between the total energy entering and the total energy leaving the system during that process.

$$\begin{pmatrix}\text{Total energy}\\ \text{entering the system}\end{pmatrix} - \begin{pmatrix}\text{Total energy}\\ \text{leaving the system}\end{pmatrix} = \begin{pmatrix}\text{Change in the total}\\ \text{energy of the system}\end{pmatrix}$$

$$E_{\mathrm{in}} - E_{\mathrm{out}} = \Delta E_{\mathrm{system}}$$

Energy Change of a System

The energy change of a system during a process is equal to the ***net work*** and heat transfer between the system and its surroundings.



Energy Change of a System, ΔE_{system}

Energy change = Energy at final state – Energy at initial state

$$\Delta E_{\text{system}} = E_{\text{final}} - E_{\text{initial}} = E_2 - E_1$$

- Energy is a property, the value of a property does not change unless the state of the system changes.
- Energy can exist in numerous forms such as internal (*sensible, latent, chemical, and nuclear*), kinetic, potential, electric, and magnetic.

Energy Change of a System

- Neglecting electric, and magnetic energy, the total energy change is

$$\Delta E = \Delta U + \Delta \mathrm{KE} + \Delta \mathrm{PE}$$

$$\Delta U = m\left(u_2 - u_1\right)$$

$$\Delta \mathrm{KE} = \tfrac{1}{2} m\left(\mathscr{V}_2^{\,2} - \mathscr{V}_1^{\,2}\right)$$

$$\Delta \mathrm{PE} = mg\left(z_2 - z_1\right)$$

Mechanism of Energy Transfer, E_{in} and E_{out}

- Energy can be transferred to or from a system in three forms: ***heat***, ***work***, and *mass flow*.
- For a fixed mass system (***closed system***), there are only two forms of energy interactions associated with the system are *heat transfer* and *work*.

Mechanism of Energy Transfer

Heat Transfer, *Q*

Heat transfer to a system (heat gain) increases the energy of the molecules and thus the internal energy of the system, and heat transfer from a system (heat loss) decrease it since the energy transferred out as heat comes from the energy of the molecules of the system.

Mechanism of Energy Transfer

Work, *W*

An energy interaction that is not caused by a temperature difference between a system and its surroundings is work. Work transfer to a system (i.e. work done on a system) increase the energy of the system, and work transfer from a system (i.e. work done by the system) decrease it since the energy transferred out as work comes from the energy contained in the system.

Mechanism of Energy Transfer

Mass Flow, *m*

Mass flow in and out of the system serves as an additional mechanism of energy transfer. When mass enters a system, the energy of the system increases because mass carries energy with it (in fact, mass is energy). Likewise, when same mass leaves the system, the energy contained within the system decreases because the leaving mass takes out some energy with it.

Energy Balance of any System

- Normal form

$$\underbrace{E_{\text{in}} - E_{\text{out}}}_{\substack{\text{Net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{\text{system}}}_{\substack{\text{Change in internal, kinetic,} \\ \text{potential, etc., energies}}}$$

- Rate form

$$\underbrace{\dot{E}_{\text{in}} - \dot{E}_{\text{out}}}_{\substack{\text{Rate of net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{\Delta \dot{E}_{\text{system}}}_{\substack{\text{Rate of change in internal,} \\ \text{kinetic, potential, etc., energies}}}$$

Energy Balance of any System

- The energy balance can be written more complicitly as

$$E_{\text{in}} - E_{\text{out}} = \left(Q_{\text{in}} - Q_{\text{out}}\right) + \left(W_{\text{in}} - W_{\text{out}}\right) + \left(E_{\text{mass, in}} - E_{\text{mass, out}}\right)$$

$$= \Delta E_{\text{system}}$$

Energy Balance for Closed System

- For a closed system undergoing a cycle where the initial and final states are identical.

$$\Delta E_{\text{system}} = E_2 - E_1 = 0$$

- For closed system there is no mass across boundaries

$$W_{\text{net, out}} = Q_{\text{net, in}} \quad \text{or} \quad \dot{W}_{\text{net, out}} = \dot{Q}_{\text{net, in}} \qquad \text{(for a cycle)}$$

Energy Balance for Closed System

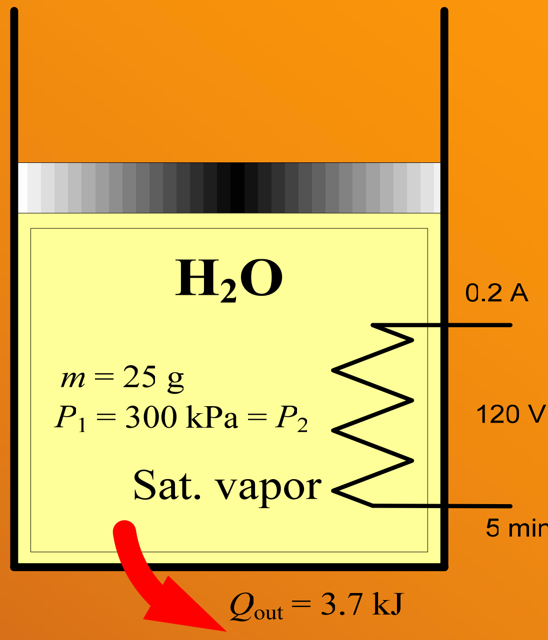
- Referring to heat and work sign convention, the energy balance relation becomes

$$Q_{\text{net, in}} - W_{\text{net, out}} = \Delta E_{\text{system}}$$

$$Q - W = E$$

Example

A piston-cylinder device contains 25 g of saturated water vapor that is maintained at a constant pressure of 300 kPa. A resistance heater within the cylinder is turned on and passes a current of 0.2 A for 5 min from a 120-V source. At the same time, a heat loss of 3.7 kJ occurs.



(a) show that for a closed system the boundary work W_b and the change in internal energy ΔU in the first-law relation can be combined into one term, ΔH, for a constant-pressure process.

(b) Determine the final temperature of the steam.

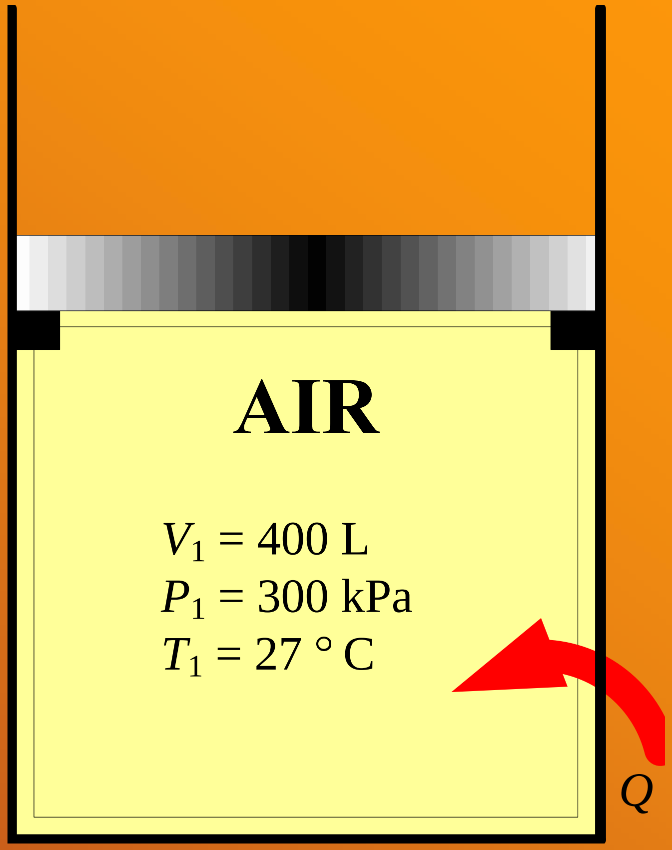
Example

A piston-cylinder device initially contains air at 150 kPa and 27°C. At this state, the piston is resting on a pair of stops, as shown, and the enclosed volume is 400 L. The mass of the piston is such that a 350-kPa pressure is require to move it. The air is now heated until its volume has doubled. Determine

(a) the final temperature,

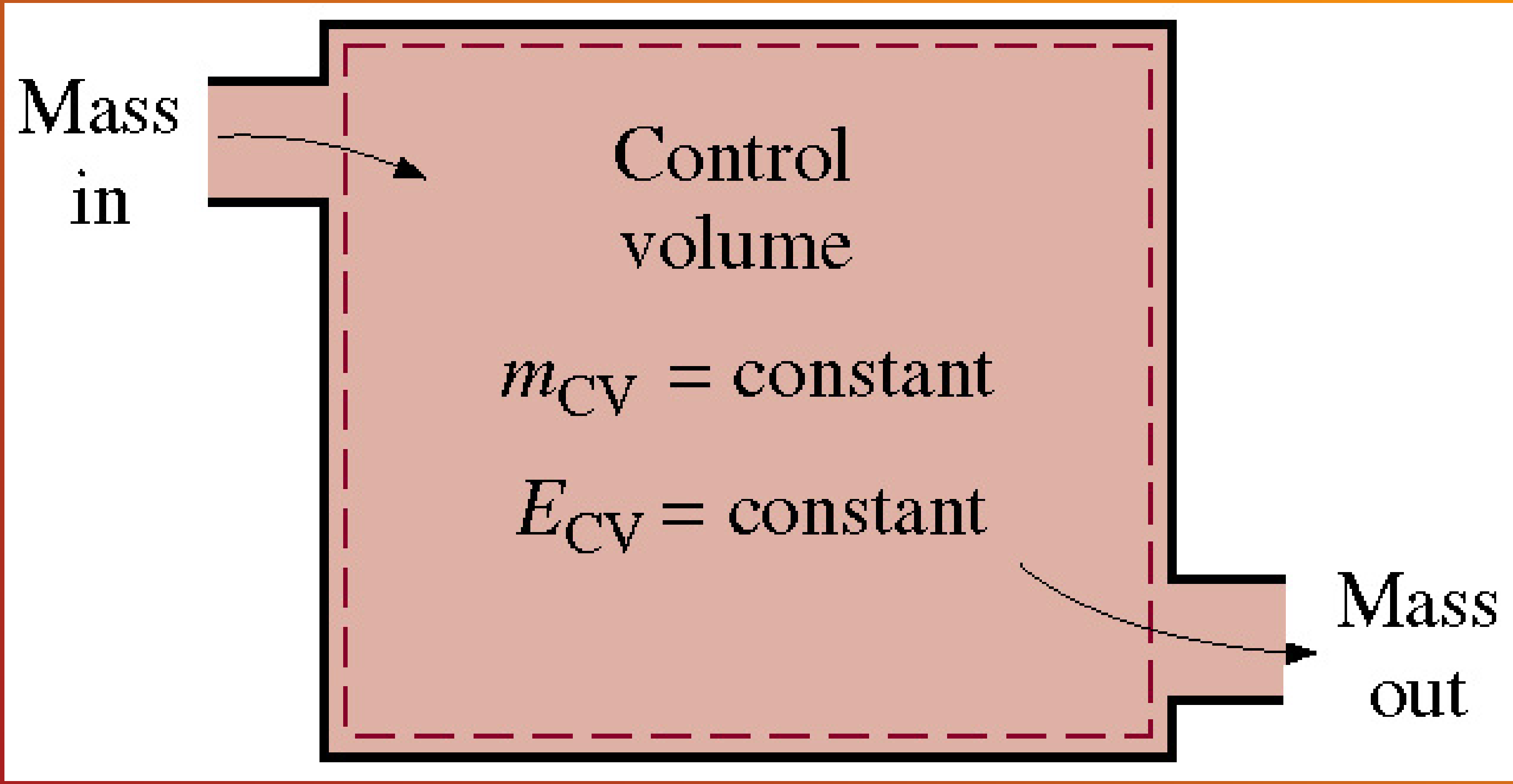
(b) the work done by the air, and

(c) the total heat transferred to the air.



Mass Balance for Steady-Flow Systems

- **Steady-flow process** -: a process during which a fluid flows through a control volume steadily.



Mass Balance for Steady-Flow Systems

- Mass balance :

$$\dot{m}_{\mathrm{in}} = \dot{m}_{\mathrm{out}} \qquad (\mathrm{kg/s})$$

  – Single inlet – Single exit

$$\dot{m}_1 = \dot{m}_2 \quad \text{or} \quad \rho_1 \mathscr{V}_1 A_1 = \rho_2 \mathscr{V}_2 A_2$$

  – Multiple inlets – Multiple exits

$$\sum \dot{m}_{\mathrm{i}} = \sum \dot{m}_{\mathrm{e}} \qquad (\mathrm{kg/s})$$

Energy Balance for Steady-Flow Systems

- During a steady-flow process, the total energy of a control volume remains constant, and thus the change in the total energy of the control volume is zero.

$$\underbrace{\dot{E}_{\text{in}} - \dot{E}_{\text{out}}}_{\substack{\text{Rate of net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{\Delta \dot{E}_{\text{system}}}_{\substack{\text{Rate of change in internal, kinetic,} \\ \text{potential, etc., energies}}} = 0$$

or

$$\underbrace{\dot{E}_{\text{in}}}_{\substack{\text{Rate of net energy transfer in} \\ \text{by heat, work, and mass}}} = \underbrace{\dot{E}_{\text{out}}}_{\substack{\text{Rate of net energy transfer out} \\ \text{by heat, work, and mass}}}$$

Energy Balance for Steady-Flow Systems

- Energy can only be transferred by heat, work, and mass, therefore energy balance equation becomes

$$\dot{Q}_{\text{in}} + \dot{W}_{\text{in}} + \underbrace{\sum \dot{m}_i \left(h_i + \frac{\mathscr{V}_i^2}{2} + g z_i \right)}_{\text{for each inlet}} = \dot{Q}_{\text{out}} + \dot{W}_{\text{out}} + \underbrace{\sum \dot{m}_e \left(h_e + \frac{\mathscr{V}_e^2}{2} + g z_e \right)}_{\text{for each exit}}$$

Mass

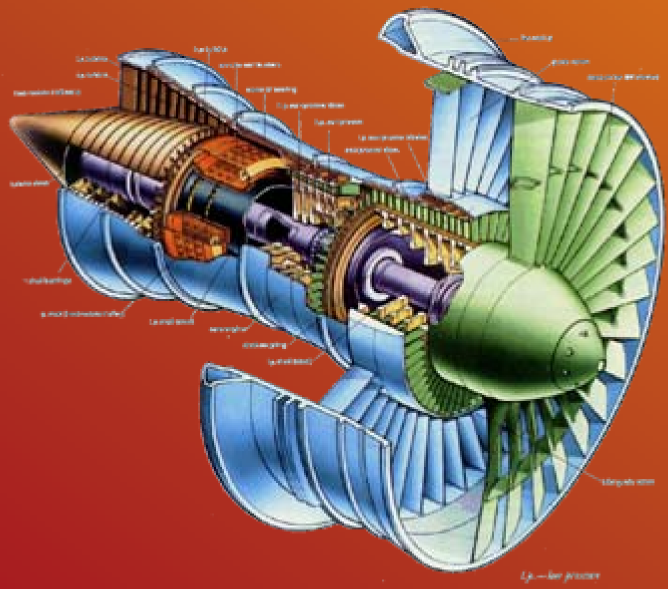
Energy Balance for Steady-Flow Systems

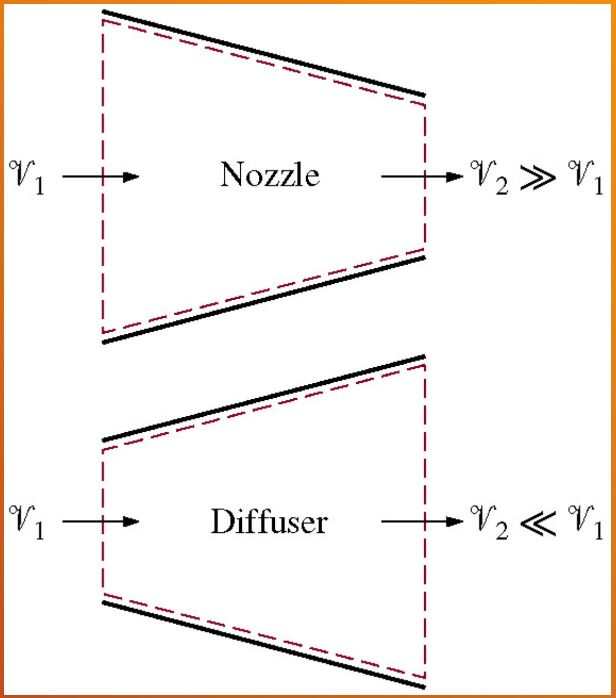
- It is common practice to assume heat to be transferred ***into the system*** (heat input) and, work produced ***by the system*** (work output), and then solve the problem.
- The first law or energy balance relation in that case for general steady-flow system becomes

$$\dot{Q} - \dot{W} = \underbrace{\sum \dot{m}_e \left(h_e + \frac{\mathscr{V}_e^2}{2} + gz_e \right)}_{\text{for each exit}} - \underbrace{\sum \dot{m}_i \left(h_i + \frac{\mathscr{V}_i^2}{2} + gz_i \right)}_{\text{for each inlet}}$$

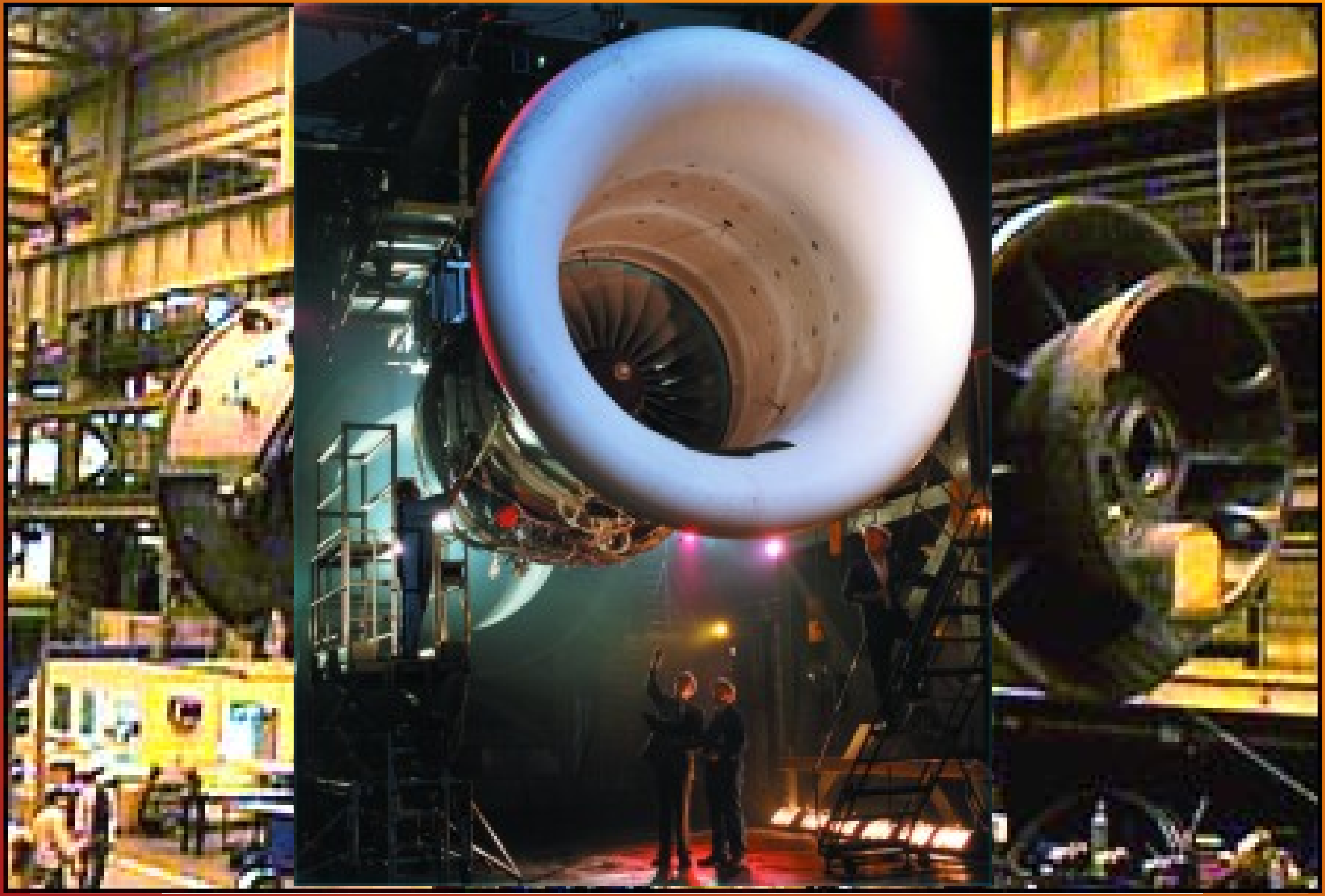
Nozzles and Diffusers

- A nozzle is a device that increases the velocity of a fluid at the expense of pressure.
- A diffusers is a device that increases the pressure of a fluid by slowing it down.





Nozzles and Diffusers



Nozzles and Diffusers

- Heat transfer is usually very small.

$$\dot{Q} \approx 0$$

- Involve no work.

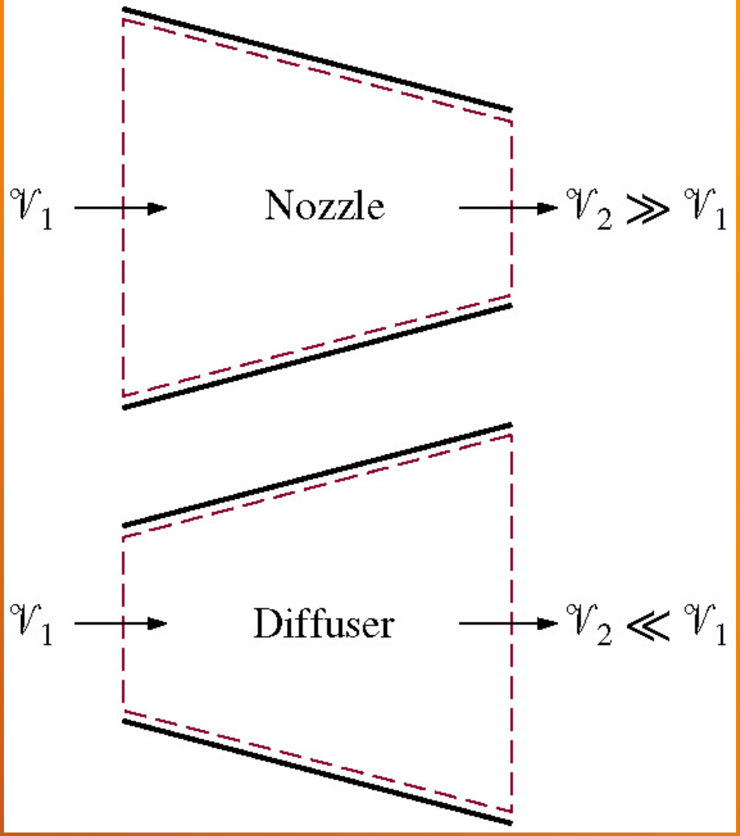
$$\dot{W} \approx 0$$

- Neglect change in potential energy.

$$\Delta pe \cong 0$$

- Involve only kinetic energy change.

$$\Delta ke \neq 0$$

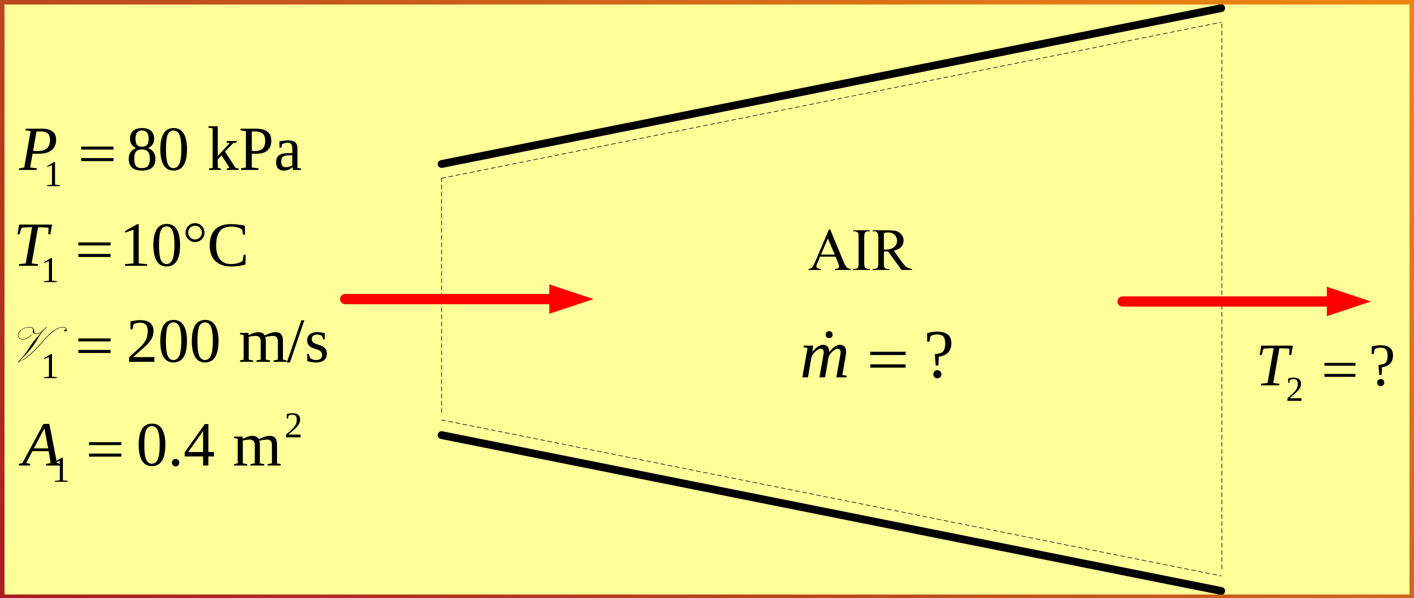


Example :-
Deceleration of Air in a Diffuser

Air at 10°C and 80 kPa enters the diffuser of a jet engine steadily with a velocity of 200 m/s. The inlet area of the diffuser is 0.4 m^2. The air leaves the diffuser with a velocity that is very small compared with the inlet velocity. Determine

(a) the mass flow rate of the air

(b) the temperature of the air leaving the diffuser.



Turbines and Compressors

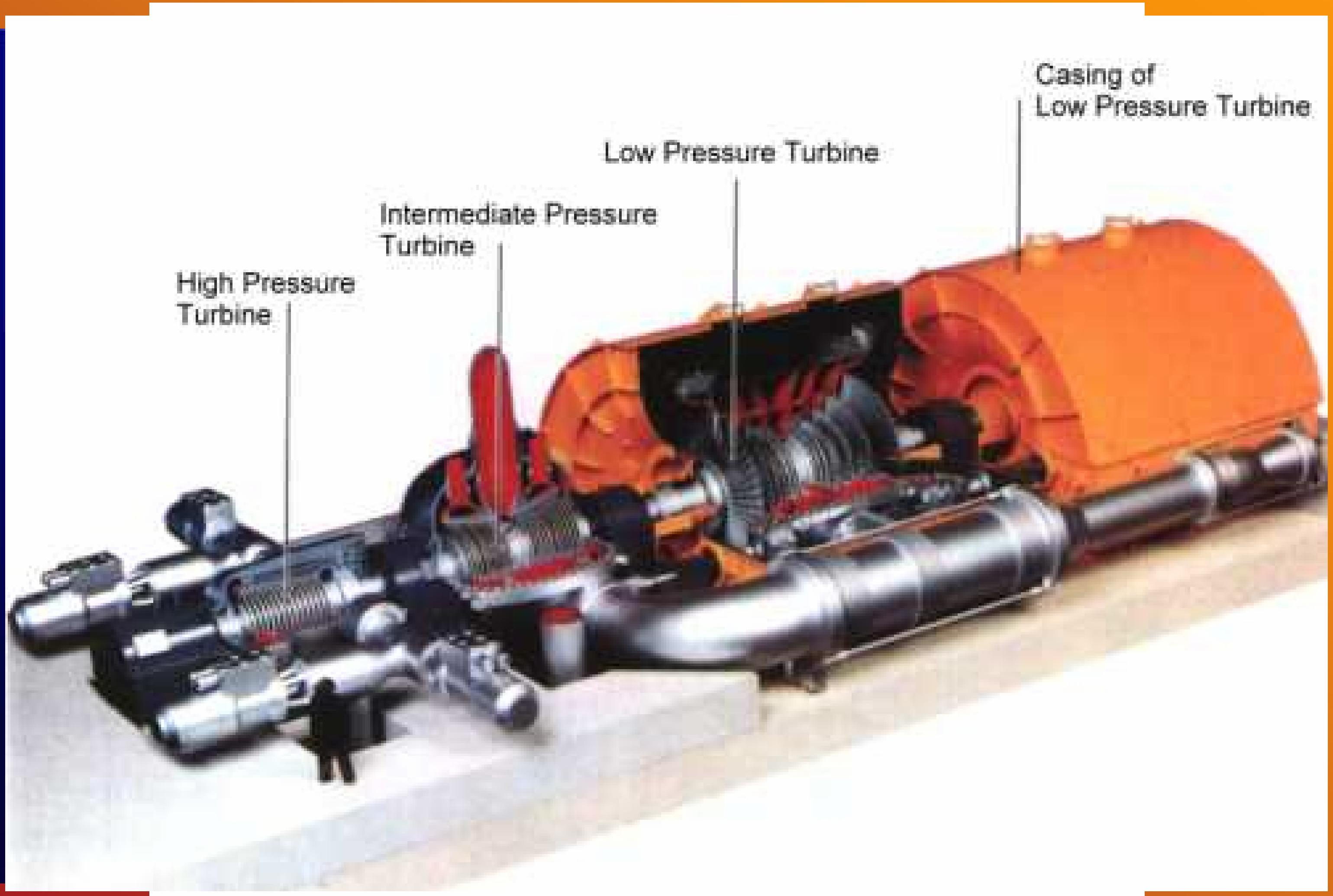
- Turbines produce ***power output***.
- Compressors, pumps, and fans require ***power input***.
- No heat transfer, change in potential and kinetic energies.

$$\dot{Q} \approx 0$$

$$\Delta \mathrm{pe} \cong 0$$

$$\Delta \mathrm{ke} \cong 0$$

Turbines


Casing of
Low Pressure Turbine
Low Pressure Turbine
Intermediate Pressure
Turbine
High Pressure
Turbine

Compressors

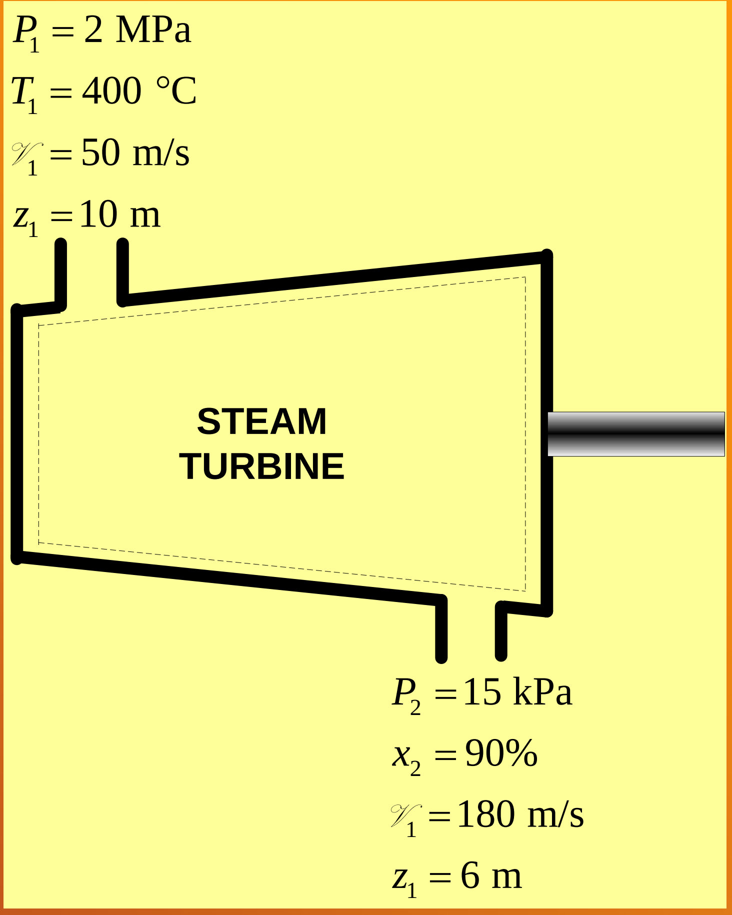
Example :-
Power Generation by a Steam Turbine

The power output of an adiabatic steam turbine is 5 MW, and the inlet and the exit conditions of the steam are as indicated in the figure.

(a) Compare the magnitudes of Δh, Δke, and Δpe.

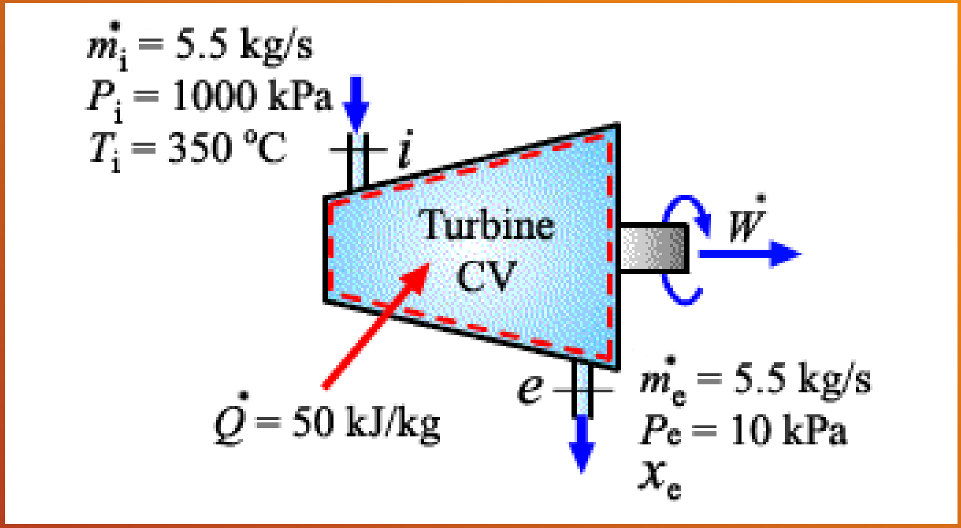
(b) Determine the work done per unit mass of the steam flowing through the turbine.

(c) Calculate the mass flow rate of the steam.



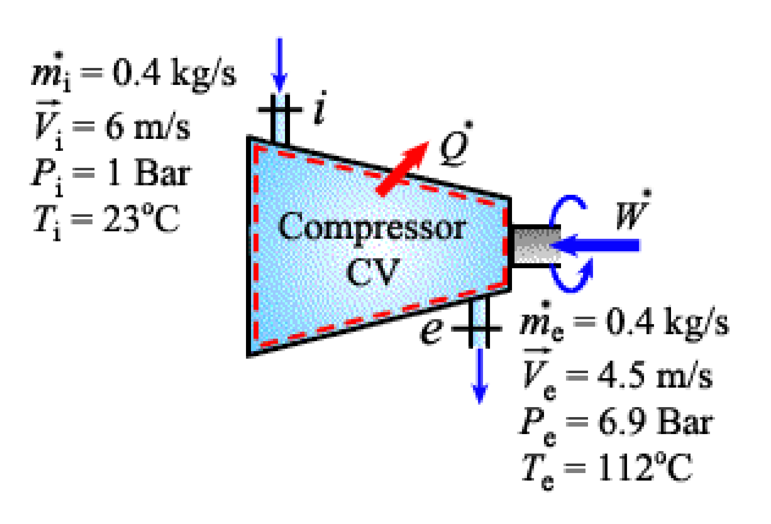
Example

A steam turbine receives steam at 1000 kPa and 350°C. The mass flow rate of the steam is 55 kg/s. The heat loss from the turbine is 50 kJ/kg of steam. It is known that the power output of the turbine is 40×10^3 kW . If the turbine exhausts at 10 kPa, determine the quality of the steam leaving the turbine.



Example

Air flows steadily at the rate of 0.4 kg/s through an air compressor, entering at 6 m/s with a pressure of 1 bar and a temperature of 23°C, and leaving at 4.5 m/s with a pressure of 6.9 bar and a temperature of 112°C. The rate of heat transfer from the compressor to the surrounding is 60 kW. Calculate the power required to drive the compressor and the inlet and the outlet pipe cross-sectional.



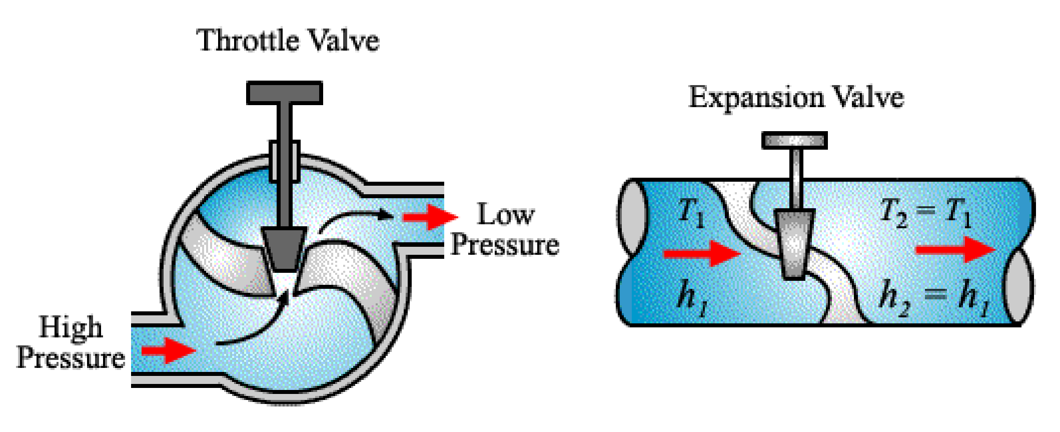
Throttling Valves

- Throttling valves are any kind of flow-restricting devices that cause a significant pressure drop in the fluid.

$$\dot{Q} \approx 0$$

$$\Delta \text{pe} \cong 0$$

$$\Delta \text{ke} \cong 0$$



$$h_2 \cong h_1 \quad (\text{kJ/kg})$$

Energy Balance for Unsteady-Flow Processes

Mass balance :-

$$\sum m_i - \sum m_e = \left(m_2 - m_2\right)_{\text{system}}$$

Energy balance :-

$$\underbrace{E_{\text{in}} - E_{\text{out}}}_{\substack{\text{Net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{\text{system}}}_{\substack{\text{Change in internal, kinetic,} \\ \text{potential, etc., energies}}}$$

$$\left(Q_{\text{in}} + W_{\text{in}} + \sum m_i h_i\right) - \left(Q_{\text{out}} + W_{\text{out}} + \sum m_e h_e\right) = \left(m_2 u_2 - m_1 u_1\right)_{\text{system}}$$

Example : Charging of Rigid Tank by Steam

A rigid, insulated tank that is initially evacuated is connected through a valve to a supply line that carries steam at 1 MPa and 300°C. Now the valve is opened, and steam is allowed to flow slowly into the tank until the pressure reaches 1 MPa, at which point the valve is closed. Determine the final temperature of the steam in the tank.