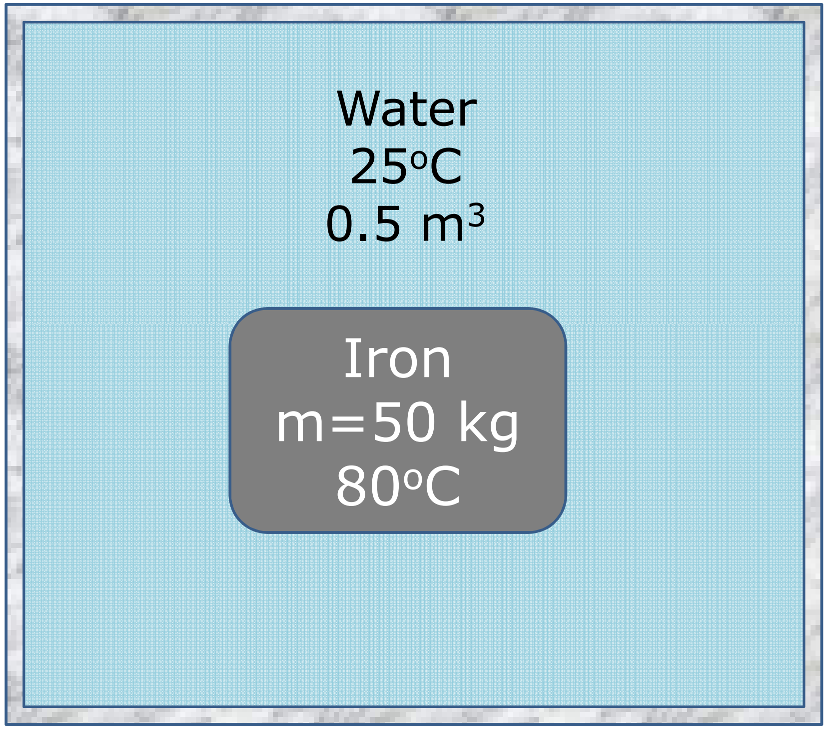
Problem 1

- A 50 kg iron block at 80°C is dropped into an insulated tank that contains 0.5 m^3 of liquid water at 25°C. Determine the temperature when thermal equilibrium is reached.

  Specific heat iron: 0.45 kJ/kg°C, specific heat of water: 4.184 kJ/kg°C

Solution: Problem 1



Solution: Problem 1

- Assumptions:
  - Both water and the iron block are incompressible substances.
  - Constant specific heats at room temperature can be used for water and the iron.
  - The system is stationary and thus the kinetic and potential energy changes are zero, $\Delta KE, \Delta PE=0$ and $\Delta E= \Delta U$.
  - There are no electrical, shaft, or other forms of work involved.
  - The system is well-insulated and thus there is no heat transfer.

Solution: Problem 1

- The energy balance can be expressed as:

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

$$0 = \Delta U$$

$$\Delta U_{system} = \Delta U_{iron} + \Delta U_{water} = 0$$

$$[mc(T_2 - T_1)]_{iron} + [mc(T_2 - T_1)]_{water} = 0$$

Mass of water, $m = V/v = 0.5\ m^3/0.001\ m^3/kg$

$$= 500\ kg$$

Solution: Problem 1

- Substituting the above values,

$(50kg)(0.45\ kJ/kg\ ^oC)(T_2 - 80^oC) + (500\ kg)(4.18\ kJ/kg\ ^oC)(T_2 - 25^oC) = 0$

Therefore, $T_2 = 25.6^oC$

This will be the temperature of water and iron after the system attains thermal equilibrium.

Note: The marginal change in the temperature of water. Why is this so?

Problem 2

- A stationary mass of gas is compressed without friction from an initial state of 0.3 m^3 and 0.105 MPa to a final state of 0.15 m^3 and 0.105 MPa. There is a transfer of 37.6 kJ of heat from the gas during the process. What is the change in internal energy of the gas during this process?

Solution: Problem 2

- From the first law for a stationary system,

$$Q = \Delta U + W$$

- In this example, the process is a constant pressure process. The work done during such a process is

$$W = \int P dV = P(V_2 - V_1)$$

$$= 0.105(0.15 - 0.30) = -15.75 \text{ kJ}$$

Solution: Problem 2

- It is given that the heat transfer from the system is $Q = -37.6\ kJ$
- Therefore, $-37.6 = \Delta U - 15.75$

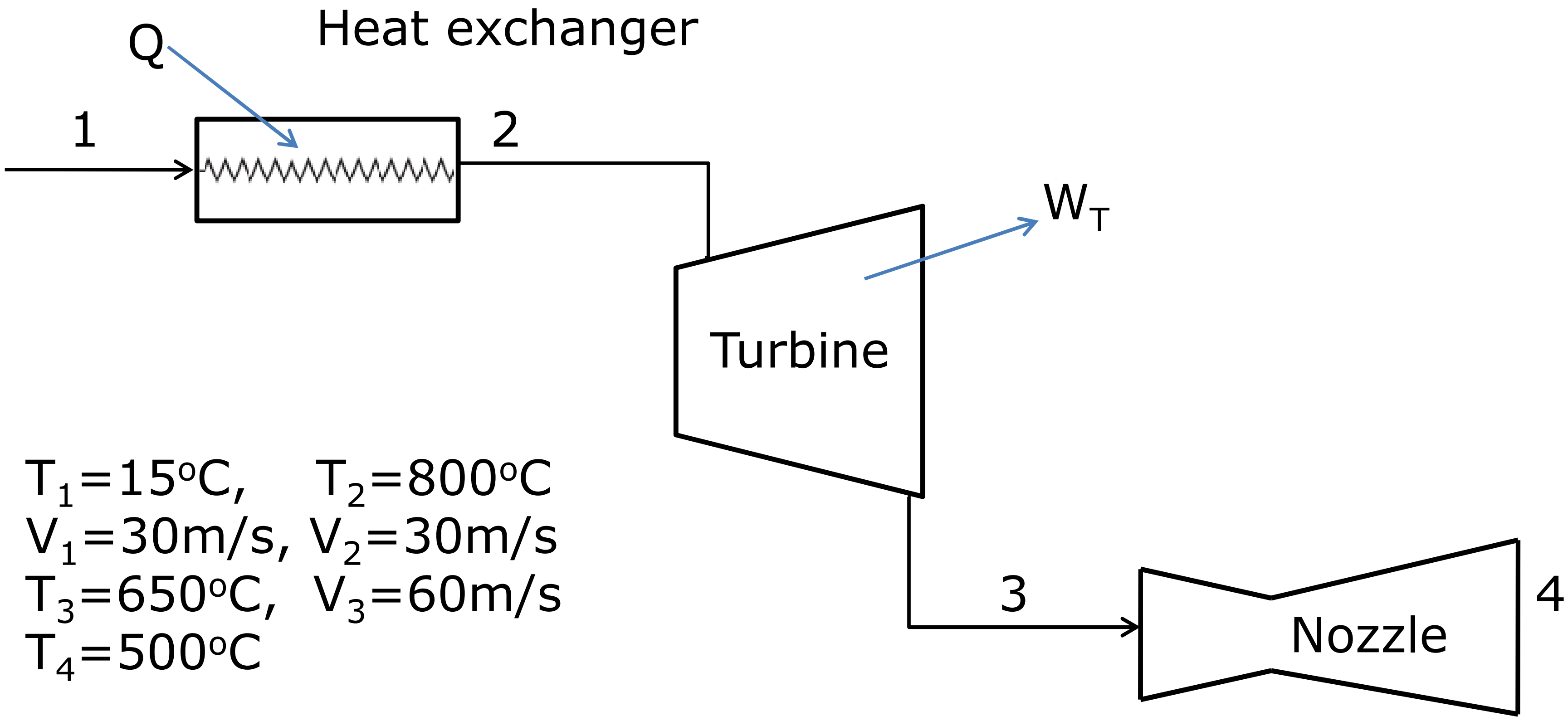
  or, $\Delta U = -21.85$ kJ

- The change in internal energy of the gas is -21.85 kJ (decrease in internal energy during the process)

Problem 3

- Air at a temperature of $15^{o}C$ passes through a heat exchanger at a velocity of 30 m/s where its temperature is raised to $800^{o}C$. It then passes through a turbine with the same velocity of 30 m/s and expands until the temperature falls to $650^{o}C$. On leaving the turbine, the air is taken at a velocity of 60 m/s to a nozzle where it expands until its temperature has fallen to $500^{o}C$. If the air flow rate is 2 kg/s, find (a) rate of heat transfer from the heat exchanger (b) the power output from the turbine (c) velocity at nozzle exit assuming no heat loss
- Assume c_p= 1.005 kJ/kg K

Solution: Problem 3



$T_1 = 15^oC$, $T_2 = 800^oC$
$V_1 = 30 m/s$, $V_2 = 30 m/s$
$T_3 = 650^oC$, $V_3 = 60 m/s$
$T_4 = 500^oC$

Solution: Problem 3

- Applying the energy equation across 1-2 (heat exchanger)

$$\dot{Q} - \dot{W} = \dot{m}\left[h_2 - h_1 + \frac{V_2^2 - V_1^2}{2} + g(z_2 - z_1)\right]$$

For a heat exchanger, this reduces to,

$$\dot{Q}_{1-2} = \dot{m}(h_2 - h_1) = \dot{m}\,c_p(T_2 - T_1)$$

$$= 2 \times 1.005 \times (1073.16 - 288.16) = 1580 \text{ kJ/s}$$

- The rate of heat exchanger to the air in the heat exchanger is 1580 kJ/s

Solution: Problem 3

- The energy equation the turbine 2-3

$$\dot{W} = \dot{m}\left[h_2 - h_3 + \frac{V_2^{\,2} - V_3^{\,2}}{2}\right]$$

$$\dot{W} = 2 \times \left[1.005 \times (1073.16 - 923.16) + \frac{(30^2 - 60^2)}{2}\right]$$

$$= 298.8\,\mathrm{kW}$$

- The power output from the turbine is 298.8 kW

Solution: Problem 3

- For the nozzle (3-4)

$$\frac{V_3^2}{2} + h_3 = \frac{V_4^2}{2} + h_4$$

$$\frac{60^2}{2} + 1.005 \times (923.16) = \frac{V_4^2}{2} + 1.005 \times (773.16)$$

$$\therefore V_4 = 554\ m/s$$

- The velocity at the exit from the nozzle is 554 m/s.

Exercise Problem 1

- A mass of 8 kg gas expands within a flexible container as per $pv^{1.2}$ = constant. The initial pressure is 1000 kPa and the initial volume is 1 m^3. The final pressure is 5 kPa. If the specific internal energy of the gas decreases by 40 kJ/kg, find the heat transfer in magnitude and direction.
- Ans: +2615 kJ

Exercise Problem 2

- 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 and (b) the temperature of* the air leaving the diffuser.
- Ans: 78.8 kg/s, 303K

Exercise Problem 3

- At the inlet to a certain nozzle, the enthalpy of the fluid passing is 3000 kJ/kg and the velocity is 60 m/s. At the discharge end, the enthalpy is 2762 kJ/kg. The nozzle is horizontal and there is negligible heat loss from it. (a) Find the velocity at the exit from the nozzle, (b) the mass flow rate if the inlet area is 0.1 m^2 and the specific volume is 0.187 m^3/kg at inlet, (c) the exit area if the nozzle if the specific volume at the nozzle exit is 0.498 m^3/kg.
- Ans: 692.5 m/s, 32.08 kg/s, 0.023 m^2

Exercise Problem 4

- A pressure cylinder of volume V contains air at a pressure of P_0 and temperature T_0. It is to be filled from a compressed air line maintained at a constant pressure P_1 and temperature T_1. Show that the temperature of the air in the cylinder after it has been charged to the pressure of the line is given by

$$T = \frac{\gamma T_1}{1 + \frac{P_0}{P_1}\left(\gamma \frac{T_1}{T_0} - 1\right)}$$

Exercise Problem 5

- A room for four persons has two fans, each consuming 0.18 kW power and three 100 W lamps. Ventilation air at the rate of 80 kg/h enters with an enthalpy of 84 kJ/kg and leaves with an enthalpy of 59kJ/kg. If each person puts out heat at the rate of 630 kJ/h, determine the rate at which heat is to be removed by a room cooler, so that a steady state is maintained in the room.
- Ans: 1.92 kW