Tutorial Sheet-3

Example 3-1

In a steady-flow system, a substance flows at the rate of 4 kg/s. It enters at a pressure of 620 kN/m^2 , a velocity of 300 m/s , internal energy 2100 kJ/kg, and specific volume 0.37 m^3/kg. It leaves the system at a pressure of 130 kN/m^2, a velocity of 150 m/s , internal energy 1500 kJ/kg and specific volume 1.2 m^3/kg. During its passage through the system the substance has a loss by heat transfer of 30 kJ/kg to the surroundings.

Determine the power of the system in kilowatts(kW) , stating whether it is from or to the system. Neglect any change in potential energy.

Solution:

Steady-flow system (open system)

Given:

$m^{\circ} = 4\ kg/s$. *mass flow rate*

$P_1 = 620\ kN/m^2$. *inlet pressure*

$P_2 = 130\ kN/m^2$. *outlet pressure*

$C_1 = 300\ m/s$. *inlet velocity*

$C_2 = 150\ m/s$. *outlet velocity*

$u_1 = 2100\ kJ/kg$. internal energy at inlet

$u_2 = 1500\ kJ/kg$, internal energy at outlet

$v_1 = 0.37\ m^3/kg$, specific volume at inlet

$v_2 = 1.2\ m^3/kg$, specific volume at out let

Heat lost, Q= 30 kJ/ kg (must be negative value)

Calculate power of system in (KW), W° =?

Potential energy= neglected i.e $g(Z_2 - Z_1)=0$

General relation of Steady flow energy equation(SFEE) for unit mass:

$$Q - W = (h_2 - h_1) + \frac{C_2{}^2 - C_1{}^2}{2} + g(Z_2 - Z_1)$$

$$h_1 = u_1 + P_1 v_1 = 2100 + 620 \times 0.37 = 2329.4 \ kJ/kg$$

$$h_2 = u_2 + P_2 v_2 = 1500 + 130 \times 1.2 = 1656 \, kJ/kg$$

$$\frac{C_2{}^2}{2} = \frac{(150)^2}{2 \times 10^3} = 11.25 \, kJ/kg$$

$$\frac{C_1{}^2}{2} = \frac{(300)^2}{2 \times 10^3} = 45 \, kJ/kg$$

$$\frac{C_2{}^2 - C_1{}^2}{2} = 11.25 - 45 = -33.75 \, kJ/kg$$

Substitute these values in general relation, we get

$$(-30) - W = (1656 - 2329.4) - 33.75$$

$$W = 677.15 \, kJ/kg$$

$$power\ of\ the\ system \quad W^{\circ} = m^{\circ} \times W = 4 \ \times 677.15$$
$$= 2708.6 \, kJ/S \quad or \quad 2708.6 kW$$

Example 3-2

10 kg of fluid per minute goes through a reversible steady flow process. The properties of fluid at the inlet are : p_1=1.5 bar , $v_1 = 0.038 \ m^3/kg$, C_1=110 m/s and u_1=910 kJ/kg and at the exit are p_2=5.5 bar, $v_2 = 0.181 \, m^3/kg$, C_2=190 m/s and u_2=710 kJ/kg. During the passage , the fluid rejects 55kJ/s and rises through 55 meters. Determine:

(i) the change in enthalpy (Δh)

(ii) Work done during the process (W).

Solution.

Mass flow rate , $m^{\circ} = 10 \ kg/\text{min} = \frac{10}{60} = 0.166 \, kg/s$

Properties of fluid at inlet :

Pressure p_1=1.5 bar

Specific volume $v_1 = 0.038 \ m^3/kg$

Velocity C_1=110 m/s

Internal energy u_1=910 kJ/kg

Properties of fluid at the exit :

Pressure p_2=5.5 bar

Specific volume $v_2 = 0.181\ m^3/kg$

Velocity C_2= 190 m/s

Internal energy u_2=710 kJ/kg

Heat rejected by the fluid , Q= 55kJ/s

The fluid is rises through 55 m, i.e Z_2 = 55 m

(i) The change in enthalpy,

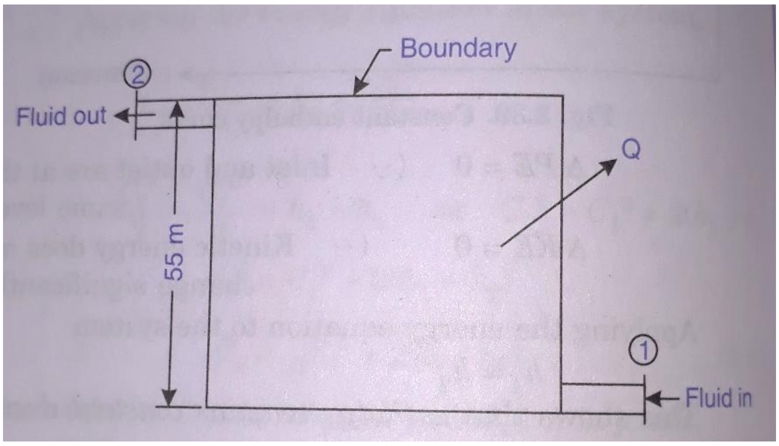
$$\Delta h = \Delta u + \Delta(pv)$$

$$\Delta(pv) = p_2v_2 - p_1v_1 = (5.5 \times 10^2) \times 0.181 - (1.5 \times 10^2) \times 0.038$$

$$= 99.55 - 5.7 = 93.85\, kJ/kg$$

$$\Delta u = u_2 - u_1 = 710 - 910 = -200\, kJ/kg$$

$$\boxed{\Delta h = \Delta u + \Delta(pv = -200 + 93.85 = -106.15\ kJ/kg)}$$ **(Ans.)**



(ii) The steady flow equation for unit mass flow can be written as

$$Q = \Delta\, KE + \Delta\, PE + \Delta\, h + W$$

Where Q is the heat transfer per kg of fluid

$$\boxed{Q^{\circ} = Q \times m^{\circ} \quad or \qquad Q = \frac{Q^{\circ}}{m^{\circ}} = \frac{55}{0.166} = 331.32\ kJ/kg}$$

Now,

$$\Delta\, KE = \frac{{C_2}^2 - {C_1}^2}{2} = \frac{(190)^2 - (110)^2}{2} = 12000\ Nm/kg\ or\ 12000 J/kg\ \ or\ 12\, kJ/kg$$

$$\Delta\, PE = (Z_2 - Z_1)g = (55 - 0)9.81 = 539.5\, Nm\, or\, J = 0.54\ kJ/kg$$

Substituting the value in steady floe equation,

$-331.32 = 12 + 0.54 - 106.15 + W$

W = - 236.77 kJ/kg

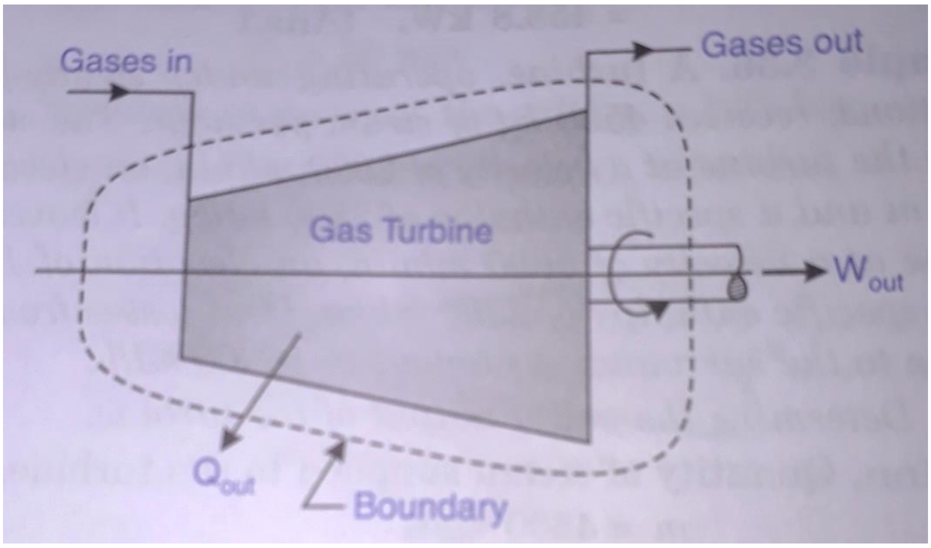
Work done per second, $W^{\circ} = m^{\circ} \times W = \mathbf{0.166 \times -236.77 = -39.30\ kW}$ (Ans.)

Example 3-3

In a gas turbine unit, the gases flow through the turbine is 15 kg/s and the power developed by the turbine is 12000 kW. The enthalpies of gases at the inlet and outlet are 1260 kJ/kg and 400 kJ/kg respectively , and the velocity of gases at the inet and outlet are 50 m/s and 110 m/s respectively. Calculate :

(i) The rate at which heat is rejected from the turbine

(ii) The area of the inlet pipe given that the specific volume of the gases at the inlet is 0.45 m^3/kg.



Solution.

Rate of flow of gases, $m^{\circ} = 15\ kg/s$

Specific volume at inlet $v_1 = 0.45\ m^3/kg$

Power developed by turbine, $W^{\circ} = 12000\ kW$

Work done, $W = \frac{W^{\circ}}{m^{\circ}} = \frac{12000}{15} = 800\ kJ/kg$

Enthalpy of gases at the inlet, h_1**= 1260 KJ/kg**

Enthalpy of gases at the outlet, h_2**= 400 KJ/kg**

Velocity of gases at the inlet, C_1**= 50 m/s**

Velocity of gases at the outlet, C_2= 110 m/s

(i) Heat rejected, Q

Using the Steady Flow Energy Equation (S.F.E.E)

Neglecting the potential energy since Z_1=Z_2

$$h_1 + \frac{{C_1}^2}{2} + Q = h_2 + \frac{{C_2}^2}{2} + W \quad …….. \qquad (1)$$

Kinetic energy at inlet

$$= \frac{{C_1}^2}{2} = \frac{50^2}{2 \times 1000} = 1 \cdot 25 \ kJ/kg$$

Kinetic energy at outlet

$$\frac{{C_2}^2}{2} = \frac{110^2}{2 \times 1000} = 6 \cdot 05 \, kJ/kg$$

Substituting these value in eqn. (1)

$$1260 + 1 \cdot 25 + Q = 400 + 6 \cdot 05 + 800$$

Q = -55.2 KJ/kg

i.e, Heat rejected = +55.2 KJ/kg

= 55.2 x 15 = 828 kW

(ii) Inlet area, A_1

Using the relation,

$$m^{\circ} = \frac{CA}{v}$$

$$\therefore \quad A_1 = \frac{v_1 m^{\circ}}{C_1} = \frac{0 \cdot 45 \times 15}{50} = 0 \cdot 135 \, m^2$$

$$A_1 = \frac{\pi d^2}{4}$$

$$0 \cdot 135 = \frac{\pi d^2}{4}$$

$$d^2 = 0 \cdot 135 \times \frac{4}{\pi} = 0 \cdot 171$$

d=0.413 m