Q1 (15 POINTS)

A table of specific internal energies of nitrogen at $P = 1$ **atm** contains the following data:

T(°C)	$\hat{U}$ (kJ/mol)
0	− 0.73
25	0.00
100	2.19
200	5.13

(a) What reference state was used to generate this table?
Answer:

nitrogen (v, 25°C, 1atm) ✓

(b) What is the physical significance of the value **2.19 kJ/mol**?
Answer:

✗ 3.5

(c) Calculate the changes in specific internal energy for the process going from **200 °C** to **100°C**?
Answer:

(v, 200°C, 1atm) ⟶ (v, 100°C, 1atm)

$\hat{u}_{Initial}$ $\hat{u}_{final}$

$\hat{u}$ reference (v, 25°C, 1atm)

$\hat{u}_{Initial} = 5.13$ KJ/mol

$\hat{u}_{final} = 2.19$ KJ/mol

$\Delta\hat{u} = 2.19 - 5.13$

$= -2.94$ KJ/mol

(d) Calculate the heat required to cool **2 mol N_2** form **200 °C** to **100°C**?
Answer:

$Q = \Delta \vec{U}$

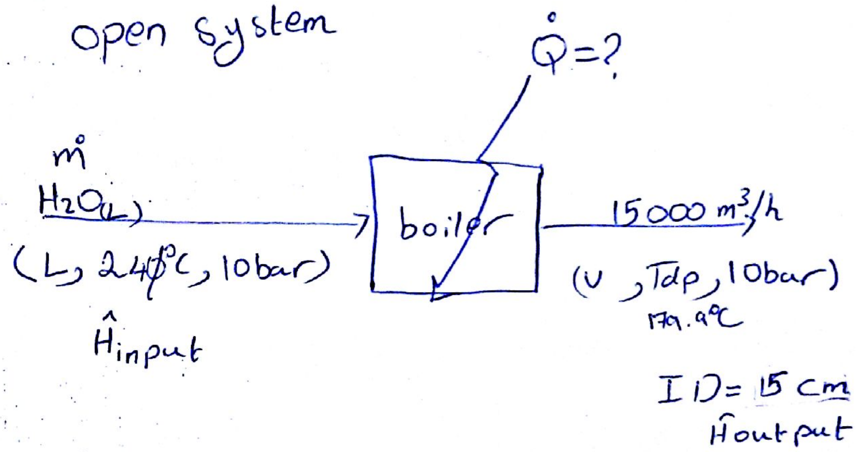
$\Delta\vec{U} = n_{\text{moles of } N_2}\,(\Delta\hat{U})$

$= 2\text{mol} \left| \dfrac{-2.94 \text{ kJ}}{\text{mol}} \right. = -5.88$ kJ

−ve Because we are cooling ✓

Q2 (15 POINTS)

Liquid water is fed to a boiler at **240°C** and **10 bar** and is converted at constant pressure to saturated steam. Calculate the heat input required to produce **15000 m3/h** of steam at the exiting conditions. Assume that the kinetic energy of the entering liquid is negligible and that the steam is discharged through a **15-cm ID** (internal diameter) pipe.



$$\Delta\dot{H} + \Delta\dot{E}_k + \cancel{\Delta\dot{E}_p} = \dot{Q} - \cancel{\dot{W}_s}$$

$$\Delta\dot{H} + \Delta\dot{E}_k = \dot{Q}$$

(specific volume for steam at 10bar) $\hat{V} = 0.1943\ m^3/kg$

$$\dot{m} = \frac{15000\ m^3}{h} \Big| \frac{1}{0.1943\ m^3/kg} \Big| \frac{1h}{3600s} = 21.5\ \frac{kg}{s}$$

$$u(m/s)_{out} = \frac{\dot{V}}{Area} = \frac{15000\ m^3}{h} \Big| \frac{1}{\pi\ (7.5cm)^2} \Big| \frac{10^4 cm^2}{1m^2} \Big| \frac{1h}{3600s}$$

$$= 236 m/s$$

$$\Delta\dot{E}_k = E_{k\,out} - E_{k\,in} = \frac{1}{2}\dot{m}\,u^2 = \frac{21.5\ kg}{2 \cdot s} \Big| \frac{236^2 m^2}{s^2}$$

$$= 598732\ kW$$

-2

$\hat{H}$ input = 762.6 kJ/kg   Table B.7

$\hat{H}$ output = 2776.2 kJ/kg   Table B.7

$$\dot{Q} = \Delta \dot{H} + \Delta \dot{E}_k$$

$$= \dot{m}(\Delta \hat{H}) + \Delta \dot{E}_k$$

$$= \frac{21.5 \text{ kg}}{s} \left| \frac{(2776.2 - 762.6) \text{ kJ}}{\text{kg}} \right. + 598732 \frac{\text{kJ}}{s}$$

$$= 642024.4 \frac{\text{kJ}}{s}$$

$\boxed{-2}$

Q3 (20 POINTS)

Superheated steam at **40 bar** absolute and **500°C** flows to a **turbine** at a rate of **250 kg/min**, and leaves the turbine as steam at **5 bar**. The turbine delivers shaft work at a rate of **1500 kW** and its operation is adiabatic. From the turbine the **steam** flows to a **heater**, where it is reheated at constant pressure to its initial temperature of **500°C**.

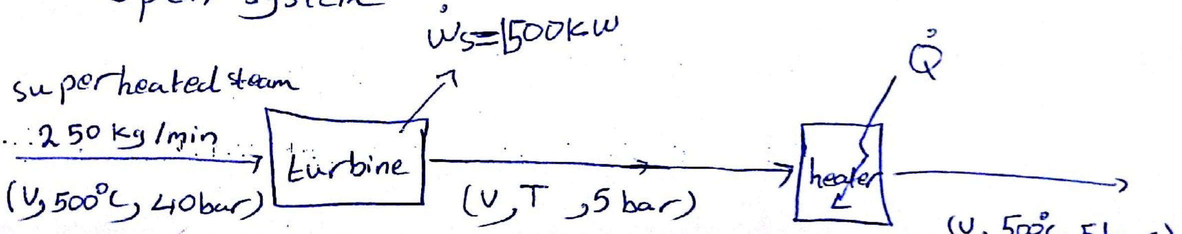
(a) Write an energy balance on the turbine and use it to determine the outlet temperature of the turbine exit stream.

(b) Write an energy balance on the heater and use it to determine its required heat input in **kW**.

(c) Verify that an overall energy balance on the two-unit (turbine followed by heater) process is satisfied.

(d) Suppose the turbine inlet and outlet pipes both have diameters of **0.5** meter. Show that it is reasonable to neglect the change in kinetic energy for this unit.

open system



$\dot{Q} = 0$

$\hat{H}_1 = 3445$ Table B.7 kJ/kg

$\hat{H}_2 =$

$\hat{H}_3 = 3434$ kJ/kg

a) $$\Delta \dot{H} + \cancel{\Delta \dot{E}_k} + \cancel{\Delta \dot{E}_p} = \cancel{\dot{Q}} - \dot{W}_s$$

$$\Delta \dot{H} = -\dot{W}_s$$

$$\dot{m}(\hat{H}_2 - \hat{H}_1) = -\dot{W}_s$$

$$\frac{250\,kg}{min} \left| \frac{1\,min}{60\,s} \right| \frac{(\hat{H}_2 - 3445)\,kJ}{kg} = -1500\,\frac{kJ}{s}$$

$$\hat{H}_2 = 3087.9\ kJ/kg$$

Table B.7

$$\frac{3168 - 3065}{350 - 300} = \frac{3087.9 - 3065}{T - 300} \rightarrow \boxed{T(\text{of exit stream}) = 311.12°C}$$

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b) $\Delta \dot{H} + \cancel{\Delta \dot{E}_k} + \cancel{\Delta \dot{E}_p} = \dot{Q} - \cancel{\dot{W}_s}$

$$\Delta \dot{H} = \dot{Q}$$

$$\dot{Q} = \dot{m} \; (\Delta \hat{H})$$

$$= \frac{250 \text{ kg}}{\text{min}} \left| \frac{1 \text{ min}}{60 \text{ s}} \right| \frac{(3484 - 3087.4) \text{ kJ}}{\text{kg}}$$

ok

$$= 1650.4 \text{ kJ/s} = 1650.4 \text{ kW}$$

c) $\Delta \dot{H} + \Delta \cancel{\dot{E}_k} + \Delta \cancel{\dot{E}_p} = \dot{Q} - \dot{W}_s$

$$\dot{Q} = \frac{250 \text{ kg}}{\text{min}} \left| \frac{1 \text{ min}}{60 \text{ s}} \right| \frac{(3484 - 3445) \text{ kJ}}{\text{kg}} + 1500 \frac{\text{kJ}}{\text{s}}$$

$$= 1662.5 \frac{\text{kJ}}{\text{s}} = 1662.5 \text{ kW}$$

When I calculate The heat input to the heater making energy Balance on heater $\dot{Q} = 1650.4$ kW and this value is close to 1662.5 kW using over all Balance so I think it is satisfied.

d) $\Delta \dot{E}_k = \dot{E}_{k\,out} - \dot{E}_{k\,in}$

$$= \frac{1}{2} \dot{m}_{out} \, u_{out} - \frac{1}{2} \dot{m}_{in} u_{in}$$

mass Balance

$\dot{m}_{in} = \dot{m}_{out} = 250$ kg/min

$$u = \frac{\dot{V}}{\text{Area}}$$

The same Area and same $\mathcal{V}$

$u_{in} = u_{out}$

$\Delta \dot{E}_k = \frac{1}{2}\dot{m}u - \frac{1}{2}\dot{m}u = 0$