Q1 (25 POINTS)

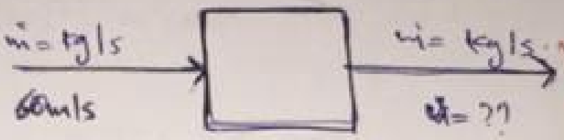
Steam at a velocity of **60 m/s** and **250°C** and **7 bar** absolute is expanded through a nozzle to 200°C and 5 bar. The nozzle has rigid (non movable) walls and its function is to increase the kinetic energy. Negligible heat is transferred from the nozzle to its surroundings.

1. Calculate the exit stream velocity?
2. Calculate the temperature and quality of the exit steam if it leaves the nozzle at a velocity of **720 m/s** and a pressure of **5 bar**

I

rigid → w = zero

−8



250°C $\dot{u}$ = 60 m/s

7 bar

$\underset{in}{\hat{H}} = 2953$ kJ/kg

u = ??

200°C

5 bar

$\underset{out}{\hat{H}} = 2855$ kJ/kg.

→ open system

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

$\Delta \dot{H} + \Delta \dot{E}_k = \text{zero}$.

$\dot{m}(\hat{H}_{out} - \hat{H}_{in}) + \frac{1}{2}\dot{m}(u_2^2 - u_1^2) = \text{zero}$ $\boxed{\dot{m}_{in} = \dot{m}_{out} = \dot{m}}$

$\frac{\dot{m}}{\dot{m}}\left((\hat{H}_{out} - \hat{H}_{in}) + \frac{1}{2}(u_2^2 - u_1^2)\right) = \frac{\text{zero}}{\dot{m}}$

$(\hat{H}_{out} - \hat{H}_{in}) + \frac{1}{2}(u_2^2 - u_1^2) = \text{zero}$

$\boxed{u_2^2 = -2(\hat{H}_{out} - \hat{H}_{in}) + u_1^2}$

$\hat{H}_{out} - \hat{H}_{in} = 2855$ kJ/kg $- 2953$ kJ/kg.

$\Delta \hat{H} = -98$ kJ/kg. ✓ kJ/kg

$u_2^2 = -2(-98)$ kJ/kg $+ 3600 \frac{m^2}{s^2}$ $\times 10^{-3}$

2

$= \frac{196 \text{ kJ}}{\text{kg}} \Big| \frac{1 \text{ N.m}}{1 \text{ J}} \Big| \frac{1 \text{ kg.m}}{1 \text{ N}} \Big| \frac{}{s^2} \Big| \frac{10^3 \text{ J}}{1 \text{ kJ}}$

$= 196 \times 10^3 \; m^2/s^2$

$u_2^2 = 196 \times 10^3 \frac{m^2}{s^2} + 3600 \frac{m^2}{s^2}$

$\boxed{u_2 = 446 \frac{m}{s}}$ #

−3

$-\hat{H}_{in}(250°C, 7 \text{ bar})$

$\frac{y_2 - y_1}{x_2 - x_1} = \frac{y_2 - y}{x_2 - x} \quad \left(\frac{(P)}{(\hat{H})}\right)$

$\frac{5 - 10}{2961 - 2943} = \frac{5 - 7}{2961 - \hat{H}}$

$-0.28 = \frac{-2}{2961 - \hat{H}}$

$-829.08 + 0.28\hat{H} = -2$

$\boxed{\hat{H} = 2953 \text{ kJ/kg}}$ #

2) $u_2 = 720\ m/s$

$P = 5\ bar$

$T = ??$

quality = ??

$$\Delta \dot{H} + \Delta \dot{E}_k = \text{zero} \longrightarrow \hat{H}_{out} = ??$$

$$\dot{m}\left(\hat{H}_{out} - \hat{H}_{in}\right) + \frac{1}{2}\dot{m}\left(u_2^2 - u_1^2\right) = \text{zero}$$

$$\left(\hat{H}_{out} - \hat{H}_{in}\right) + \frac{1}{2}\left(u_2^2 - u_1^2\right) = \text{zero} \longrightarrow \hat{H}_{out} = -\frac{1}{2}\left(u_2^2 - u_1^2\right) + \hat{H}_{in}$$

$$\left(\hat{H}_{out} - 2953\right) + \frac{1}{2}\left((720)^2 - (60)^2\right) = \text{zero}$$

$$\hat{H}_{out} = -\frac{1}{2}\left(514.8\ \frac{m^2}{s^2}\right) + 2953\ \frac{kJ}{kg}$$

$$\cancel{\hat{H}_{out} = -257.4\ \frac{m^2}{s^2} \left| \frac{1 N.m}{1 J} \right| \frac{1 kg.m}{1 N} \left| \frac{}{s^2} \right.}$$

$$\hat{H}_{out} = -257.4\ \frac{m^2}{s^2} \left| \frac{1 J}{1 N.m} \right| \frac{1 N}{1 kg.m} \left| \frac{s^2}{} \right| \frac{1 kJ}{10^3 J} + 2953\ \frac{kJ}{kg}$$

-5

$$\boxed{\hat{H}_{out} = 2953\ kJ/kg} \#$$

* Interbolation : T (5 bar, 2953 kJ/kg)
(2.12)

$$\frac{2855 - 2961}{200 - 250} = \frac{2855 - 2953}{200 - T^\circ}$$

$$424 - 2.12\,T^\circ = -98$$

$$\boxed{T^\circ = 246^\circ C} \#$$

$$\text{quality} = \frac{\text{mass kg}}{\text{Total kg}} =$$

in	out
$250^\circ C$	$246^\circ C$
7 bar	5 bar
$u_1 = 60\ m/s$	$u_2 = 720\ m/s$

Q2 (25 POINTS)

Steam at a rate of **200 kg/min** enters a turbine at **350°C** and **40 bar** through a **7.5-cm** internal diameter pipe. The turbine operation is adiabatic, and the effluent leaves as saturated water at **5 bar** through a **5-cm** diameter pipe.

1. Calculate the work produced by the turbine in **kW**.
2. What is the enthalpy and phase of the effluent stream?
   - **2.1** If it leaves the turbine at **75°C** and **5 bar**
   - **2.2** If it leaves the turbine at **30°C** and **5 bar**

7.5 — 5

saturated water

200 kg/min → turbine → 200 kg/min

- 350°C
- 40 bar
- 7.5 Cm

$\hat{H} = 3095$ kJ/kg ✓

$Q = $ zero

$W = ??$ kW

$\hat{H} = 2107.4$ kJ/kg

- 5 bar
- 5 Cm

open system

in = out

$m_{in} = m_{out} = 200$ kg/min

−18

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

$\Delta \dot{H} + \Delta \dot{E}_p = -\dot{W}$

$\dot{m}(\hat{H}_{out} - \hat{H}_{in}) + \dot{m}g(z_{out} - z_{in}) = W$

$$W = \frac{200\,kg}{min}\left|\frac{\overset{-987.6}{(2107.4 - 3095)}\,kJ}{kg}\right. + \frac{200\,kg}{min}\left|\frac{9.81\,m}{s^2}\right|\overset{-2.5}{(5 - 7.5)}\,Cm$$

⇓

$$\frac{200\,kg}{min}\left|\frac{-987.6\,kJ}{kg}\right|\frac{2.778\times10^{-7}\,kW.h}{1J}\left|\frac{10^3 J}{1\,kJ}\right|\frac{60\,min}{1\,hr} = -3.29\,kW \#$$

$$\Rightarrow \frac{200\,kg}{min}\left|\frac{9.81\,m}{s^2}\right|\frac{-2.5\,Cm\ \ 1J}{1N.m}\left|\frac{1N}{1\,kg.m/s^2}\right|\frac{2.778\times10^{-7}\,kW.h}{1J}\left|\frac{60\,min}{1\,h}\right|\frac{1\,m}{10^2 Cm} = -8.2\times10^{-4}\,kW$$

$-W = -3.29\,kW + -8.2\times10^{-4}\,kW$

$-W = -3.29\,kW \longrightarrow \boxed{W = 3.29\,kW}$

−9

$\hat{H} = \hat{u} + p\hat{V}$

2.1 : (75°C , 5 bar) $\hat{H}$.

~~$\hat{H} = 314.3$ kJ/kg~~

~~phase →~~

$\hat{H} = 314.3$ kJ/kg.

phase = superheated

2.2 : (30°C , 5 bar) ~~$\hat{H} = \hat{u} + 5$ bar~~

- 5 bar = 5×10^5 pa.

$\hat{H} = \hat{u} + p\hat{V}$

$$\hat{H} = 125.7 \frac{kJ}{kg} + \frac{5\,bar \,|\, 0.001004\,m^3}{|\, kg}$$

- gas constant :

$$8.314 \frac{m^3 \cdot Pa}{(mol \cdot K)} = 8.314 \frac{J}{(mol \cdot K)} \quad \frac{}{m^3 \cdot pa}$$

$$\hat{H} = 125.7 \frac{kJ}{kg} + \frac{5 \times 10^3\,pa \,|\, 0.001004\,m^3 \,|\, 1\,J \,|\, kJ}{|\, kg \,|\, m^3 \cdot pa \,|\, 10^3\,J} \quad 1 = 1 \frac{J}{m^3 \cdot pa}$$

$\boxed{\hat{H} = 125.7 \text{ kJ/kg}}$

phase = saturated water

.7