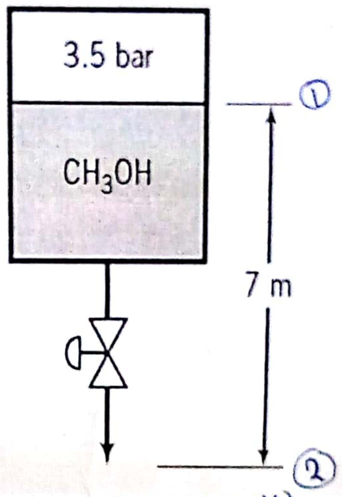
Q1 (25 POINTS)

Methanol is contained in a large tank under a pressure of **3.1 bar** absolute as shown in the following figure. When a valve on the bottom of the tank is fully opened, the methanol drains freely through a **1-cm ID** tube whose outlet is **7.0 m** below the surface of the methanol. The pressure at the outlet of the discharge pipe is **1 atm**. Determine:

1. The methanol discharge velocity.
2. The methanol flow rate in **L/min**.

MEB (2-1)



0 (large tank)

$$\frac{P_2-P_1}{\rho} + g(z_2-z_1) + \frac{1}{2}(u_2^2-u_1^2) = \frac{\dot{W}_s}{\dot{m}}$$

no shaft work, no pumps

$$\frac{P_2-P_1}{\rho} + g(z_2-z_1) + \frac{1}{2}u_2^2 = 0$$

~~3.5 bar × 1 atm / 1.01325 bar = 3.4 atm = P_1~~

~~3.4 atm = P_1~~

SG methanol = 0.792

$\rho_{methanol}$ = 0.792 × 1000 kg/m³ = 792 kg/m³
$\rho_{ref\ water}$

~~(1 − 3.4) / 792~~

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$$\frac{3.5\ \text{bar}}{} \left| \frac{1.01325\times10^5\ (\text{pa})}{1.01325\ \text{bar}} \right. = 3.5\times10^5\ (\text{pa})\ N/m^2$$

~~1 atm~~

$$1\ \text{atm} = 1.01325\times10^5\ N/m^2\ (Pa)$$

$$\frac{(1.01325\times10^5 - 3.5\times10^5)\ N}{m^2} \left| \frac{m^3}{792\ Kg} \right. = -3.1\times10^2\ J/Kg$$

$$\frac{P_2 - P_1}{\rho} = \boxed{-3.1\times10^2\ J/Kg}$$

$$g(z_2 - z_1) = \frac{9.81\ m}{s^2} \left| (0-7)\ m \right| \frac{1N}{Kg.m/s^2} = \boxed{-68.7\ J/Kg}$$

$$\frac{P_2 - P_1}{\rho} + g(z_2 - z_1) + \frac{1}{2}u_2^2 = 0$$

$$\frac{-3.1\times10^2\ J}{Kg} + \frac{-68.7\ J}{Kg} + \frac{1}{2}u_2^2 = 0$$

$$\frac{757.4\ N.m}{Kg} \left| \frac{Kg.m/s^2}{1N} \right. = \sqrt{757.4\ m^2/s^2} = \sqrt{u_2^2}$$

(1)

$$\boxed{u_2 = 27.52\ m/s}$$

$$A = \frac{1}{4}\pi D^2 = \frac{1}{4}\times\pi\times \frac{1\ cm}{} \left| \frac{10^{-2}\ m}{1\ cm} \right. = \boxed{7.8\times10^{-3}\ m^2}$$

$$\dot{V} = uA = \frac{27.52\ m}{s} \left| 7.8\times10^{-3}\ m^2 \right. = \boxed{0.21\ m^3/s}$$

(2)

$$\frac{0.21\ m^3}{s} \left| \frac{1000\ L}{1\ m^3} \right. = 210\ L/s \times \frac{1\ min}{60\ s} = \boxed{3.5\ L/min}$$

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Q2 (25 POINTS)

A **15 m3/min** stream of steam at **350 °C** and **40.0 bar** flows through a cooler. The stream is cooled until the pressure drops to **2.2 bar** as saturated steam.

1. How much heat was transferred from the steam (**kW**)?
2. What is the temperature of the exiting stream?

If the stream is cooled until the pressure drops to **2.2 bar** and **60%** of the steam condenses in the process.

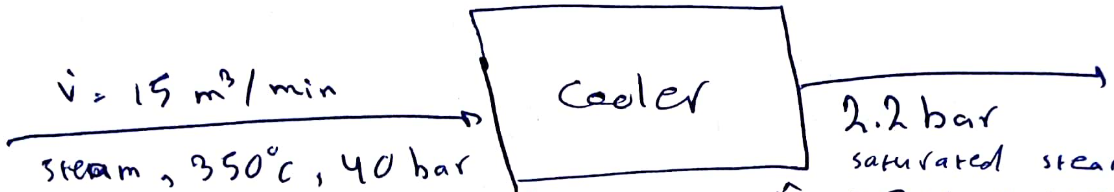
3. How much heat was transferred from the steam (**kW**)?
4. What are the volumetric flow rates of water and steam (**m³/min**)?

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

$\dot{m}_{in} = \dot{m}_{out} = \dot{m}$

Steady state

(1)



$\dot{V} = 15\ m^3/min$

steam, 350°C, 40 bar

$\hat{H}_{in} = 3095\ KJ/Kg$

$\hat{V} = 0.0665\ m^3/Kg$

from table B.6

2.2 bar

saturated steam.

$\hat{H}_{out} = 2710.6\ KJ/Kg$

from table B.6

$\Delta\dot{H} = \dot{m}(\hat{H}_{out} - \hat{H}_{in})$

$\dot{m} = \frac{\dot{V}}{\hat{V}} = \frac{15\ m^3/min}{0.0665\ m^3/Kg} = 225.6\ Kg/min$ ÷ 60 s $= 3.75\ Kg/s$

$\Delta\dot{H} = 3.75\ \frac{Kg}{s}\left(2710.6\ \frac{KJ}{Kg} - 3095\ \frac{KJ}{Kg}\right)$

$\Delta\dot{H} = -1441.5\ KW$

$\Delta\dot{H} + \dot{E}_k + \dot{E}_p = \dot{Q} - \dot{W}_s$ (no V change, no elevation change; no shaft work, pump)

$\Delta\dot{H} = \dot{Q} =$ ~~1441.5~~ $-1441.5\ KW = \dot{Q}$ heat transfered from the steam (1)

(2) stream out is saturated steam, then it's on the boiling point at 2.2 bar

it's temperature is 123.3 C°

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3- 0.6 liquid saturated & 0.4 steam saturated

(3)

at 2.2 bar

$\hat{H}_{in} = 3095$ kJ/kg

$\hat{H}_{out} = 0.6 \times \hat{H}_{\text{saturated liquid}} + 0.4 \times \hat{H}_{\text{saturated steam}}$

$\hat{H}$ saturated liquid at 2.2 bar = 517.6 kJ/kg

$\hat{H}$ saturated steam at 2.2 bar = 2710.6 kJ/kg

$\hat{H}_{out} = 0.6 \times 517.6 + 0.4 \times 2710.6 =$
$310.6 + 1084.2 = 1394.8$ kJ/kg ($\hat{H}_{out}$)

$\Delta \dot{H} = Q$

$\Delta \dot{H} = \dot{m}(\hat{H}_{out} - \hat{H}_{in})$

$= \frac{3.75 \text{ kg}}{s}\left(\frac{1394.8 \text{ kJ}}{\text{kg}} - \frac{3095 \text{ kJ}}{\text{kg}}\right)$

$= -6375.8$ kW

Q = −6375.8 kW

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(4)

$\dot{m} = \frac{\dot{V}}{\hat{V}}$

From table B.6

$\hat{V}$ at 2.2 bar steam = 0.810 m³/kg / $\hat{V}$ at 2.2 bar liquid = 0.001064 m³/kg

$\dot{m} = 3.75$ kg/s

$\dot{m}_{liquid} = 0.6 \times 3.75 = 2.25$ kg/s

$\dot{m}_{steam} = 0.4 \times 3.75 = 1.5$ kg/s

$\dot{V}_{liquid} = 0.144$ m³/min

Liquid: $\dot{V} = \hat{V} \times \dot{m} = 0.001064 \text{ m}^3/\text{kg} \times 2.25 \text{ kg/s} \times \frac{60 \text{ s}}{1 \text{ min}}$ = 0.144 m³/min

Steam: $\dot{V} = \hat{V} \times \dot{m} = \frac{0.810 \text{ m}^3}{\text{kg}} \times \frac{1.5 \text{ kg}}{s} \frac{60 \text{ s}}{1 \text{ min}} =$ **1.215 m³/min**

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