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LEVEL 4

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SEMESTER 2

MODULE CODE: M4X01166
Physical Science for Materials

ASSESSMENT TYPE: COURSEWORK

ASSESSMENT/COMPONENT: 2 / 2

COMPONENT WEIGHTING: 30 %

MODULE TUTOR: Dr R Alexander + Dr A Marotin

Attempt all questions

SUBMISSION DETAILS:

Date set: 26th April 2019

Date to submit: 31st May 2019

Materials Part (50 marks)

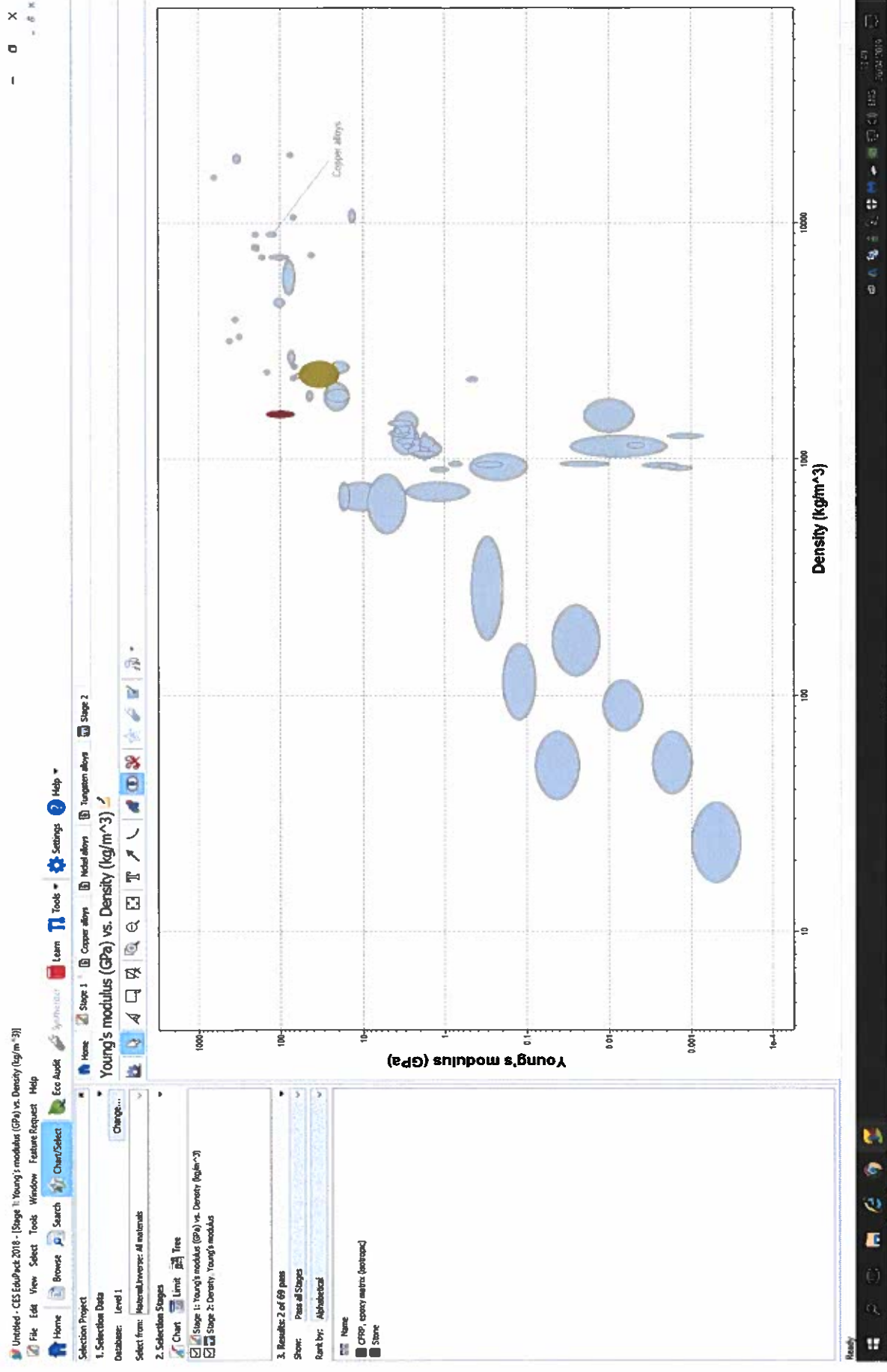
Using CES EDUPACK material selection charts, produce a chart of Young's Modulus against density and analyse the information on the chart to select materials with the given profile. This involves first creating the chart, then applying the appropriate box or line selection and reading off the materials that lie on the appropriate side of the line. It is a good idea to present the results as a table. You can copy this table from the CES EduPack. The software offers links to processes, allows a wider search by using the Level 3 database, and gives access to supporting information

- a. A component is at present made from a brass, a copper alloy, Use a Young's modulus – Density (E- ρ) chart to suggest three other metals that, in the same shape, would be stiffer. "Stiffer" means a higher value of Young's modulus.
- b. Use a Young's modulus – Density (E- ρ) chart to identify materials with both a modulus $E > 50$ GPa and a density $\rho < 2000 \text{ kg/m}^3$.
- c. Use a Young's Modulus-Density (E- ρ) chart to find (i) metals that are stiffer and less dense than steels and (ii) materials (not just metals) that are both stiffer and less dense than steel.
- d. Use a E- ρ chart to identify metals with both $E > 100 \text{ GPa}$ and $E/\rho > 0.02 \text{ GPa/(kg/m}^3\text{)}$.
- e. E5.5 Use a E- ρ chart to identify materials with both $E > 100 \text{ GPa}$ and

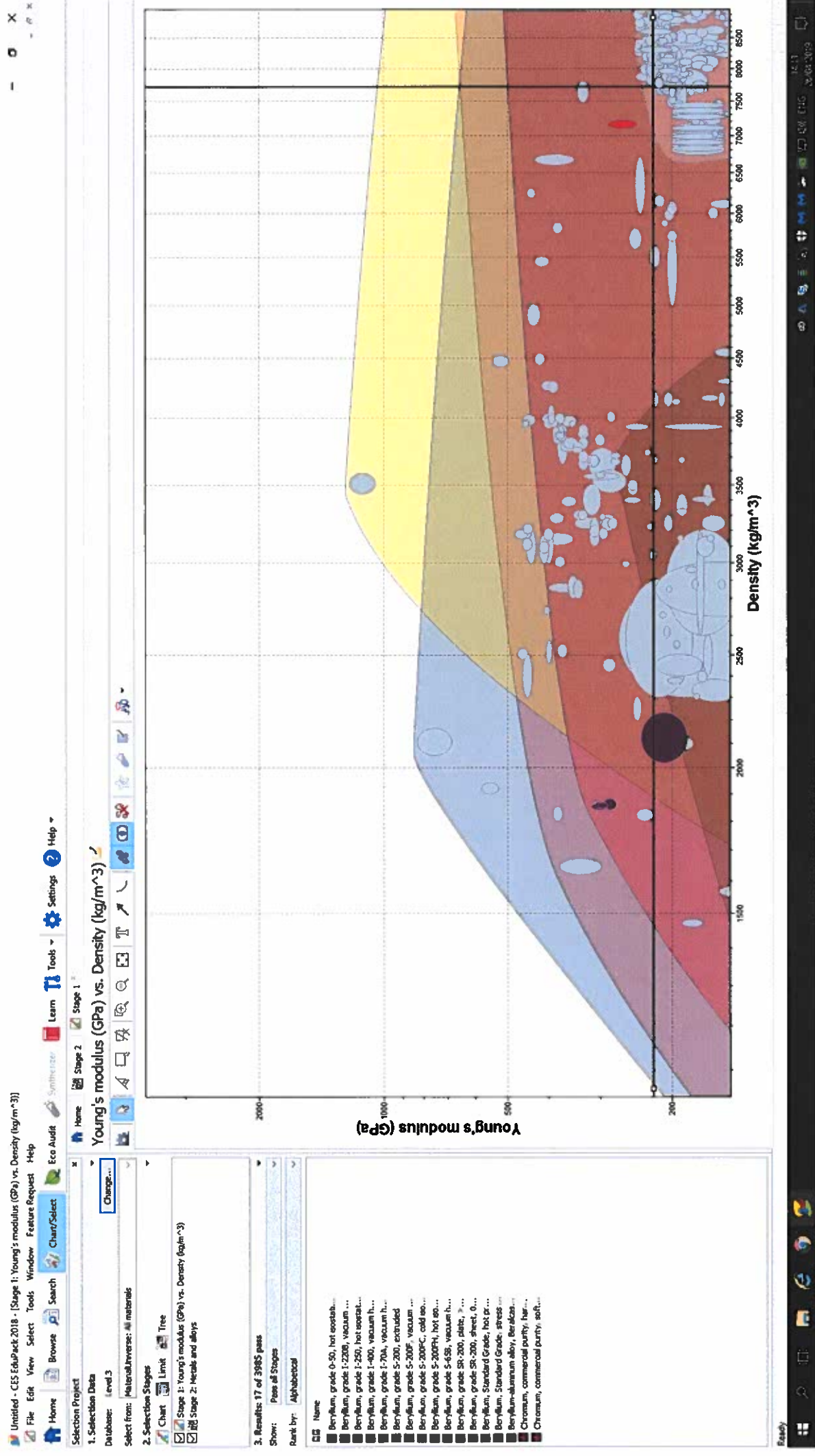
$E / \rho^{1/3} > 0.003 \text{ (GPa)}^{1/3} / (\text{kg/m}^3)$. Remember that, on taking logs, the index $M E / \rho = 1/3$ becomes $\text{Log} (E) = 3 \text{ Log} (\rho) + 3 \text{ Log} (M)$ and that this plots as a line of slope 3 on the chart, passing through the point $E = 27$ when $\rho = 1000$ in the units on the chart.

THE FOLLOWING 6 PAGES CONTAIN
GRAPHS RELATING TO THE 6 QUESTIONS
(a,b,c.i,c.ii,d & e) POSED IN THE
ASSIGNMENT. ON THE LEFT OF EACH
GRAPH IS A LIST OF THE MATERIALS THAT
MEET THE GIVEN CRITERIA.

ASSIGNMENT MATERIALS PART, QUESTION (b.)



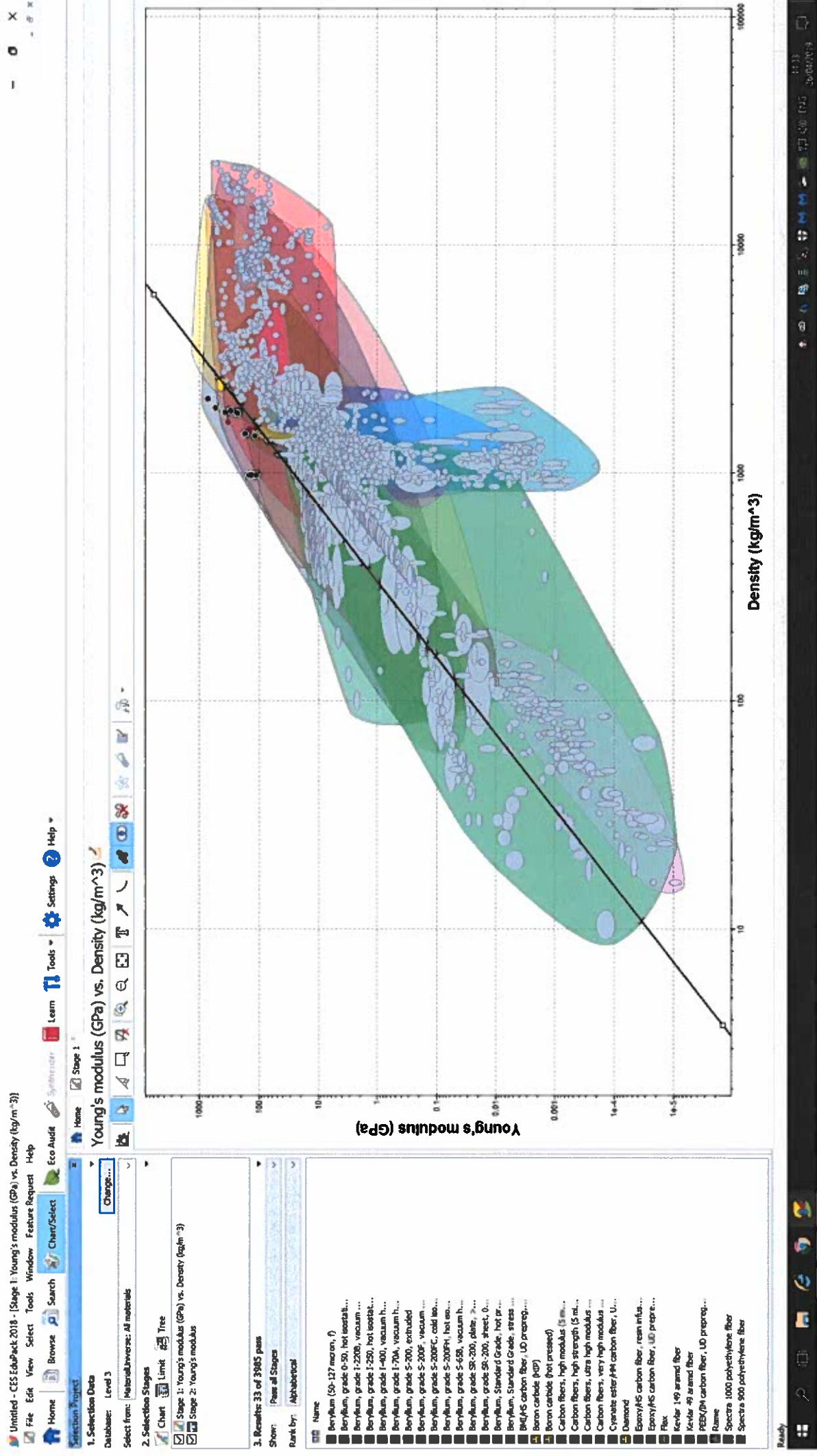
ASSIGNMENT MATERIALS PART, QUESTION (c.)



Untitled - CES EduPack 2018 [Stage 1: Young's modulus (GPa) vs. Density (kg/m³)]



ASSIGNMENT MATERIALS PART, QUESTION (e.)



QUESTION ONE (25 marks): Closed System

A cylinder contains 0.45 m^3 of oxygen at $2 \times 10^5 \text{ N/m}^2$ and 90°C . The gas is compressed to a volume of 0.3 m^3 , the final pressure being 5.5 bar. Knowing that the process is polytropic, determine,

- The mass of the gas. [3]
- If the process is Isobaric, Isothermal, Isometric or Isentropic. [7]
- The increase in internal energy of the gas. [10]
- The heat received or rejected by the gas during compression. [5]

Assumptions:

- Oxygen can be considered as an ideal gas.

Polytropic Process of Gases:

The relationship between the pressure and volume during compression or expansion of gases are often related by,

$$P \cdot V^n = C$$

where n and C are constants.

A thermodynamic process described by the above equation is called a **Polytropic** process.

For a Polytropic process between two states 1 and 2 we have,

$$P_1 \cdot V_1^n = P_2 \cdot V_2^n = C$$

When $n = 0$, $P = C$, and the process is a constant pressure process or an **Isobaric** process.

When $n = 1$, $PV = C$, and the process is a constant temperature process or an **Isothermal** process.

When $n \rightarrow \infty$, the process is called an **Isometric** process.

When $n = k$, the process is called an **Isentropic** process.

The total boundary work done during the entire process is,

$$W_b = \int_1^2 P dV = \frac{P_2 \cdot V_2 - P_1 \cdot V_1}{1 - n}$$

For the special case of $n = 1$ the boundary work becomes,

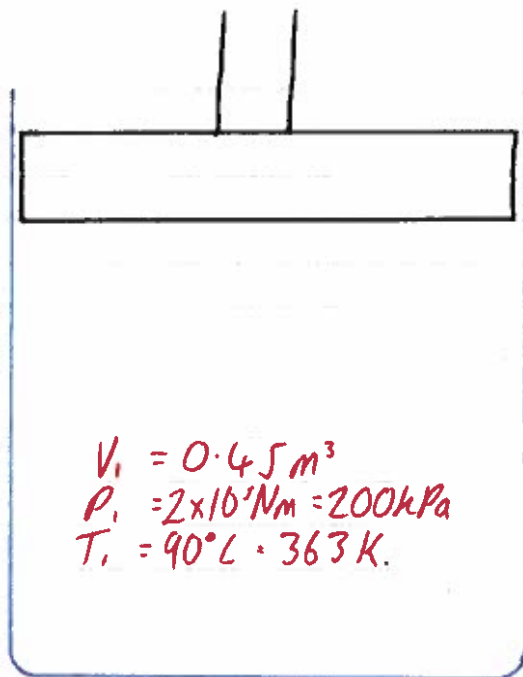
$$W_b = \int_1^2 P dV = P_1 \cdot V_1 \cdot \ln\left(\frac{V_2}{V_1}\right) = P_2 \cdot V_2 \cdot \ln\left(\frac{V_2}{V_1}\right)$$

Also V_2/V_1 can be replaced by P_1/P_2 for this case since $P_1 \cdot V_1 = P_2 \cdot V_2$.

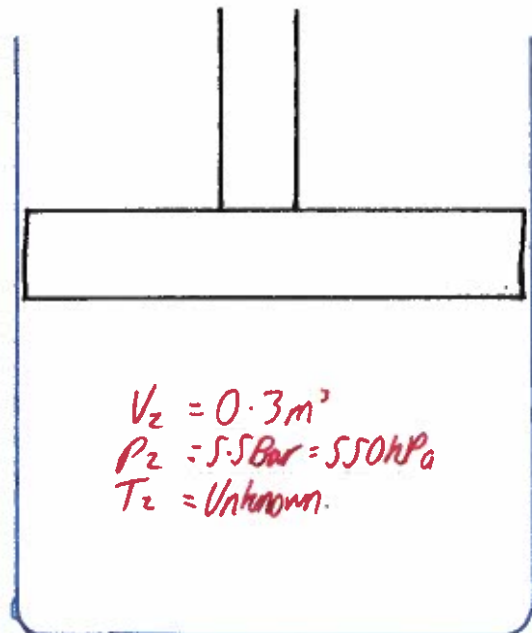
ASSIGNMENT Q1 THERMODYNAMICS

SCHEMATIC AND RELEVANT INFORMATION.

INITIAL CONDITION



FINAL CONDITION



⑨. USING THE IDEAL GAS FORMULA,

$$P.V. = R.T.$$

WHERE $P = 200 \text{ kPa}$
 $V = 0.45 \text{ m}^3/\text{kg}$
 $R = 0.2598 \text{ kJ/kg}$
 $T = 363 \text{ K}$

$$200 \times \frac{0.45}{m} = 0.2598 \times 363$$

$$200 \times 0.45 = m(0.2598 \times 363)$$

$$m = \frac{200 \times 0.45}{0.2598 \times 363}$$

$$m = 0.954 \text{ kg.}$$

b.

THE PROCESS IS ISENTROPIC
AS THERE IS NO HEAT OR
MATTER TRANSFER ACROSS
THE BOUNDARY OF THE
SYSTEM

$$(C) \quad P_2 V_2 = R_2 T_2$$

WHERE:-

$$P_2 = 550 \text{ kPa}$$

$$V_2 = 0.3 / 0.954 = 0.314$$

$$R_2 = 0.2598$$

$$T_2 = \text{Unknown.}$$

$$T_2 = \frac{550 \times 0.314}{0.2598}$$

$$= 664.74 \text{ K}$$

$$\text{OR} = 391^\circ \text{C.}$$

FROM THIS WE CAN USE $\Delta U = C_v \Delta T$ TO CALCULATE THE INCREASE IN INTERNAL ENERGY.

$$\Delta U = C_v \Delta T$$

$$= 0.658 \times (391.7 - 90)$$

$$= 198.52 \text{ kJ.}$$

(d) TO CALCULATE THE HEAT RECEIVED/REJECTED BY THE GAS WE CAN USE

$$\Delta U = Q - W$$

WHERE:-

$$\Delta U = 198.52$$

$Q = \text{Unknown}$

$$W_b = \frac{(550 \times 0.3) - (200 \times 0.45)}{1 - 1.395}$$

$$= -189.87.$$

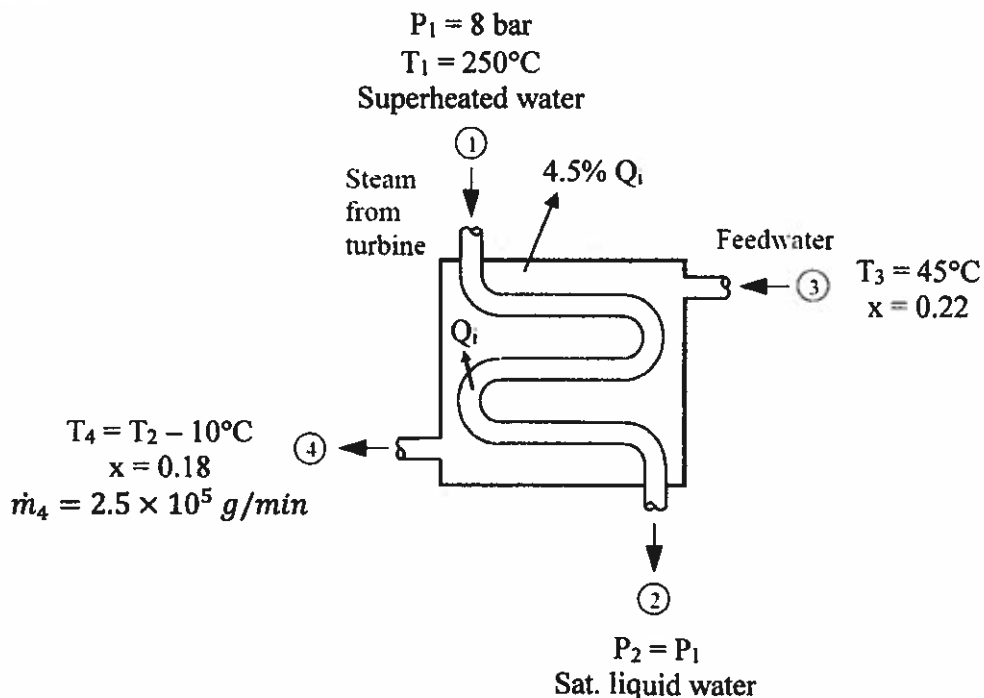
$$\therefore Q = 198.52 + (-189.87)$$
$$= 8.65 \text{ kJ RECEIVED.}$$

QUESTION TWO (25 marks): Steady-Flow Open System

In large steam power plants, the feedwater is frequently heated in closed feedwater heaters, which are basically heat exchangers, by steam extracted from the turbine at some stage. Steam enters the feedwater heater at 8 bar and 250°C as superheated water and leaves as saturated liquid water at the same pressure. Feedwater enters the heater at 45°C and a quality of 22% and leaves 10°C below the exit temperature of the steam with a quality of 18% and a mass flow rate of 2.5×10^5 g/min. If the heat losses from the outer surfaces of the heater are 4.5% of the heat given up by the steam, determine,

- The temperature at the feedwater outlet 2.
- The heat transfer rate from the steam to the feedwater.
- The mass flow rates of the extracted steam $\dot{m}_s$.

Schematic:



Assumptions:

- Steady-flow process.
- Kinetic and potential energy changes are negligible.
- There are no work interactions.
- The properties of steam and feedwater can be found in Tables A-4 through A-6.
- In a saturated liquid-vapour mixture, the mass fraction of vapour is called the *quality* and is expressed as:

$$x = \frac{m_{\text{vapour}}}{m_{\text{total}}}$$

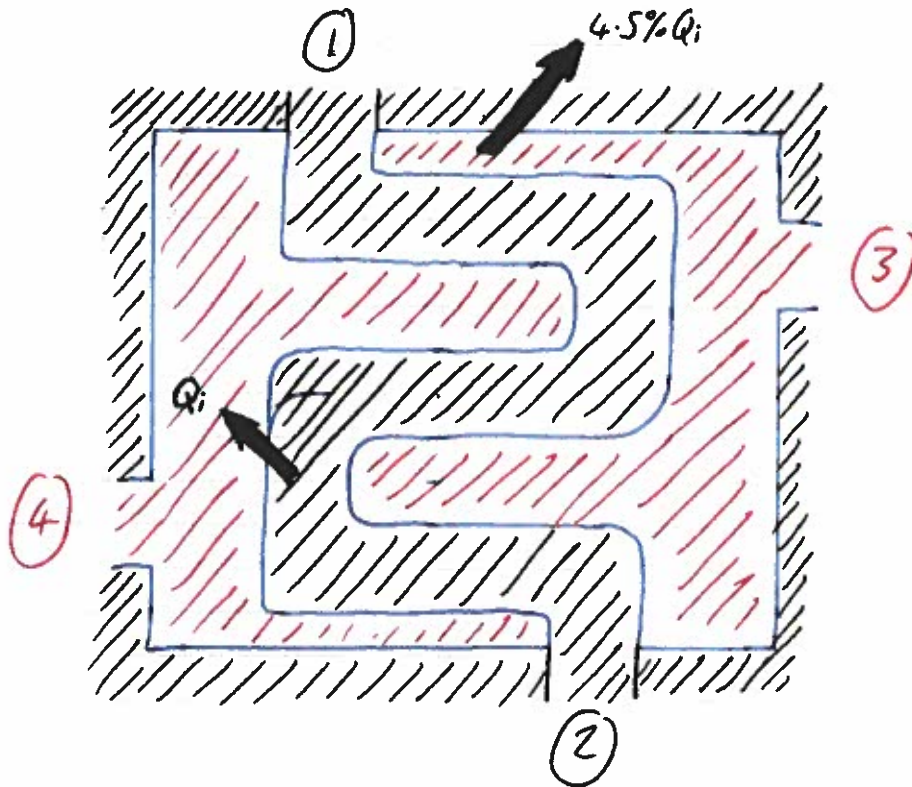
Quality may have values between 0 (saturated liquid) and 1 (saturated vapour). It has no meaning in the compressed liquid or superheated vapour regions. In the saturated mixture region, the average value of any intensive property y is determined from:

$$y = y_f + x \cdot y_{fg}$$

where f stands for saturated liquid, g for saturated vapour and y stands for v , u or h .

TO SOLVE THE
PROBLEM, 3 SEPARATE
SYSTEMS NEED TO BE
CONSIDERED

TANK SYSTEM.



————— = BOUNDARY
 /// = SYSTEM
 \\\ = SURROUNDING.

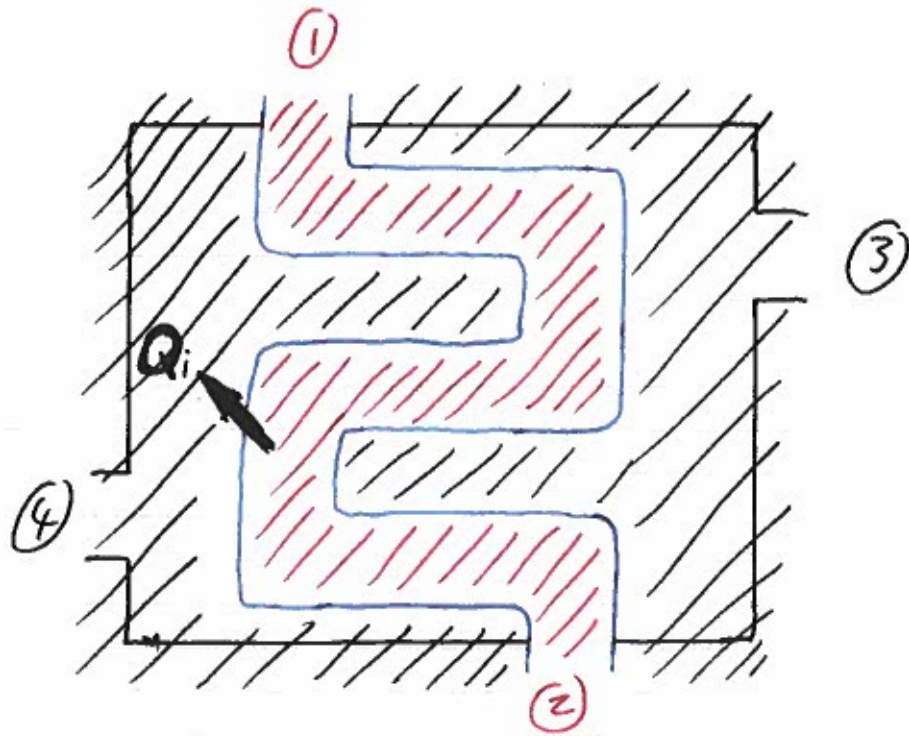
MASS BALANCE

$$\dot{m}_2 = \dot{m}_4$$

ENERGY BALANCE.

$$\dot{Q}_i - 0.045 \dot{Q}_i = \dot{m}_4 h_4 - \dot{m}_2 h_3$$

PIPE SYSTEM



— = BOUNDARY
////// = SYSTEM.
////// = SURROUNDING.

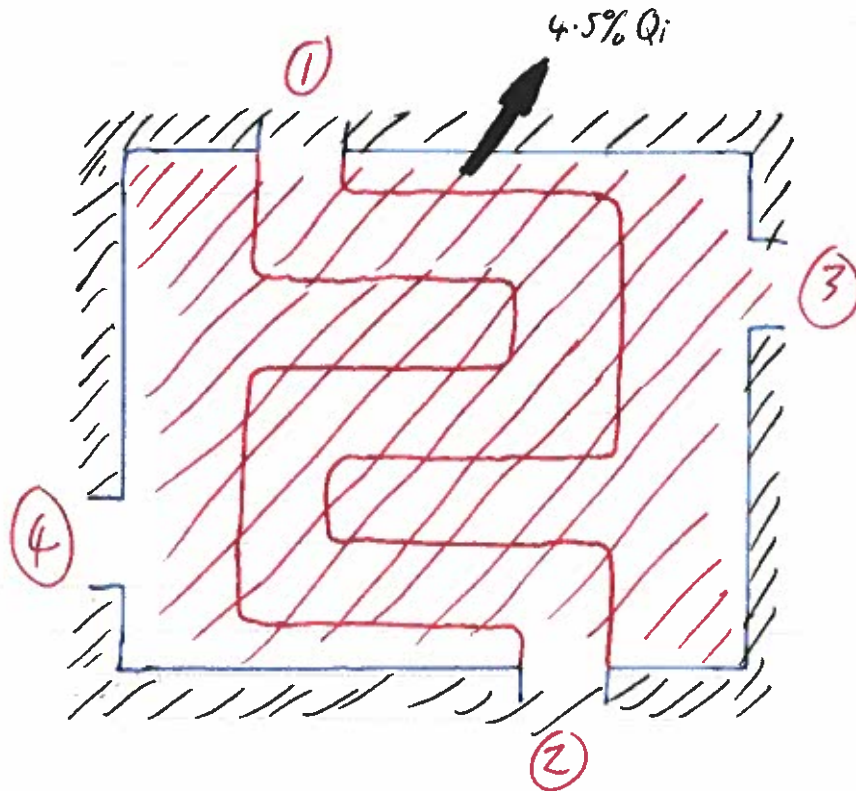
MASS BALANCE

$$\dot{m}_1 = \dot{m}_2$$

ENERGY BALANCE

$$-Q_i = \dot{m}_2 h_2 - \dot{m}_1 h_1$$

COMPLETE SYSTEM



— = BOUNDARY
////// = SYSTEM
////// = SURROUNDING.

MASS BALANCE.

$$\begin{cases} \dot{m}_1 = \dot{m}_2 \\ \dot{m}_3 = \dot{m}_4 \end{cases}$$

ENERGY BALANCE

$$- 0.045 Q_i = \dot{m}_2 h_2 + \dot{m}_4 h_4 - (\dot{m}_1 h_1 + \dot{m}_3 h_3)$$

ENTHALPY VALUES OBTAINED
FROM TABLES.

$$h_1 = 2950 \text{ kJ/kg}$$

$$h_2 = 720.87 \text{ kJ/kg}$$

$$\begin{aligned} h_3 &= h_f + (0.22 h_{fg}) \\ &= 188.4 + (0.22 \times 2394.0) \\ &= 715.12 \text{ kJ/kg} \end{aligned}$$

$$\begin{aligned} h_4 &= h_f + (0.18 h_{fg}) \\ &= 675.47 + (0.18 \times 2082.0) \\ &= 1050.23 \text{ kJ/kg.} \end{aligned}$$

USING TABLE (A5),
T2=<170 DEGREES C,
THEREFORE
T4=160 DEGREES C

TO CALCULATE THE HEAT
TRANSFER FROM THE STEAM
TO THE FEEDWATER, THE
TANK SYSTEM WAS USED

TANK SYSTEM ENERGY BALANCE.

$$\dot{Q}_i - 0.045 \dot{Q}_i = \dot{m}_4 h_4 - \dot{m}_3 h_3$$

$$\text{As } \dot{m}_3 = \dot{m}_4, -$$

$$\begin{aligned}\dot{Q}_i - 0.045 \dot{Q}_i &= \dot{m}_4 (h_4 - h_3) \\ &= 4.16 \times (1050.23 - 682.924)\end{aligned}$$

$$0.955 \dot{Q}_i = 1528$$

$$\dot{Q}_i = 1528 / 0.955$$

$$\dot{Q}_i = 1600 \text{ kJ/kg}$$

THE Q_i VALUE CAN THEN BE
USED TO DETERMINE BOTH
 m_1 AND m_2

ENERGY BALANCE

$$-Q_i = \dot{m}_2 h_2 - \dot{m}_1 h_1$$

$$= \dot{m}_1 (h_2 - h_1)$$

$$-1600 = \dot{m}_1 (720.87 - 2950.4)$$

$$= \dot{m}_1 \times (-2229.53)$$

$$\dot{m}_1 = \frac{-1600}{-2229.53}$$

$$\dot{m}_1 = 0.717 \text{ kg/s}$$

$$\therefore \dot{m}_2 = 0.717 \text{ kg/s}$$

SUMMARY

- THE TEMPERATURE AT THE FEEDWATER OUTLET 2 IS 160 DEGREES C.
- THE HEAT TRANSFER RATE FROM STEAM TO FEEDWATER IS 1600kJ/KG
- THE MASS FLOW RATES OF THE EXTRACTED STEAM ARE:-

$$m_1 \text{ AND } m_2 = 0.717\text{KG/S}$$

$$m_3 \text{ AND } m_4 = 4.16\text{KG/S}$$