Heat and Thermodynamics - Course PI 25

SELF EVALUATION ANSWER SHEET

PI 25-1 - SELF EVALUATION ANSWER SHEET

1. (a) Heat is a form of energy in a substance. The energy depends on the temperature of the substance, the type of substance, its state and the amount of mass involved.

   (b) Temperature is a measure of the ability of a substance to lose or gain heat when compared to another substance.

   (c) Enthalpy is the total heat per kg of substance, measured above a reference point.

2. (a) Saturation temperature - the temperature at which boiling occurs for a given pressure.

   (b) Subcooled liquid - liquid water at a temperature lower than the saturation value.

   (c) Saturated liquid - liquid at the saturation temperature; no vapor present.

   (d) Wet steam - liquid and vapor existing as some mixture at the saturation temperature.

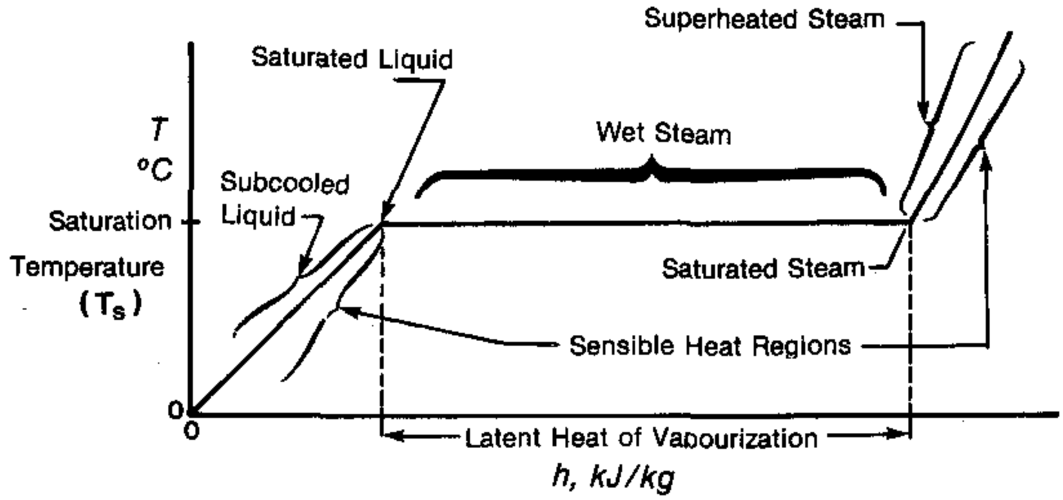
   (e) Saturated steam - vapor at the saturation temperature; no liquid is present.

   (f) Superheat steam - vapor at a temperature higher than the saturation value.

   (g) Sensible heat - heat added or removed that results in a change in temperature.

   (h) Latent heat of vaporization - heat added to boil/kg of liquid at constant temperature.

3.



4. (a) superheated steam
   (b) wet steam
   (c) subcooled liquid
   (d) saturated liquid
   (e) wet steam
   (f) saturated steam

5. Here, $\Delta h = h_{ws} - h_{f95°C}$

and, $h_{ws} = h_{f_{194°C}} + (1 - 0.13)\ h_{fg_{194°C}}$

$= h_{f_{194°C}} + 0.87\ h_{fg_{194°C}}$

Thus, $\Delta h = h_{f_{194°C}} + 0.87\ h_{fg_{194°C}} - h_{f95°C}$

$= 825.4 + 0.87 \times 1961.7 - 398.0$

$= 2134.1$ kJ/kg

The heat added is $Q = m\Delta h = 10 \times 2134.1 = \underline{2.13 \times 10^4 \text{ kJ}}$

PI 25-2 - SELF EVALUATION ANSWER SHEET

1. Here, $L_o = 500$ m

$\alpha = 10 \times 10^{-6}\ °C^{-1}$

$\Delta T = 200 - 20 = 180°C$

Thus, $L = L_o\ \alpha\ \Delta T = 500 \times 10 \times 10^{-6} \times 180$

$= \underline{0.9\ m}$

2. The switch will move towards the ON contact as it is heated. This is because the linear expansion coefficient is greater for brass than for iron; since the strip is heated, the brass will be longer. The brass must be on the outside of the arc formed, and the strip will bend to the left.

3. The volume of the wet steam is:

$v_{WS} = v_{f_{33°C}} + (1 - 0.10)\ v_{fg_{33°C}} = 1.0053 + 0.90 \times 28040.9$

$= 25240\ \ell/kg$

The volume of the water is:

$v_{f_{33°C}} = 1.0053\ \ell/kg$

The ratio is 25240 ÷ 1.0053 = 25,100 times.

4. (a) As the liquid is heated (and its temperature increases) it will expand. This is swell.

As the liquid is cooled (and its temperature decreases) its volume will decrease. This is shrink.

(b) The apparent volume of water in an operating boiler is due to the volume of liquid <u>plus</u> the volume of vapor contained in the liquid at <u>any</u> instant.

If the steam flow experiences a rapid increase, the boiler pressure suddenly decreases, the rate of vapor production increases, and the apparent volume of water in the boiler will increase. This causes the boiler level to suddenly increase. This increase is apparent volume and level is known as swell in the boiler.

If the steam flow experiences a rapid decrease, the boiler pressure will suddenly increase. The vapor present in the liquid will condense, and the apparent volume of water will suddenly decrease. This decrease and the consequent drop in boiler level is called shrink in the boiler.

5. The programmed boiler level increases as power increases and it decreases as power decreases. There are two reasons for this:

   (a) As the amount of boiling changes, so does the level. The more boiling that occurs, the more vapor is present with the liquid. The volume of water increases, and the level does also. The reverse is true as less boiling occurs. In order to maintain a constant mass of water in the boiler, the level setpoint must be increased.

   (b) The programmed level is changed more than would naturally occur (as in (a)). This is done to accommodate shrink and swell. Thus, since at a low power level swell is likely to occur, the programmed level setpoint is low. At high power levels, when shrink is likely to occur, the programmed level setpoint has been increased.

6. The use of cold lake water enables the condenser to be at 30°C and 4 kPa(a). The water flows through the condenser tubes at a maximum about 20°C, thus condensing the steam on the outside of the tubes at about 30°C. While condensing at this temperature, the steam decreases in volume in the order of 25,000 times. This will maintain the pressure at about 4 kPa(a).

PI 25-3 - SELF EVALUATION ANSWER SHEET

1. The enthalpy difference on the steam side is:

$$h_{ws_{173°C}} - h_{f_{155°C}} = h_{f_{173°C}} + (1-0.705)\ h_{fg_{173°C}} - h_{f_{155°C}}$$

$$= h_{f_{173°C}} + 0.295\ h_{fg_{173°C}} - h_{f_{155°C}}$$

The enthalpy difference on the feedwater side is:

$$h_{f_?} - f_{f_{149°C}}$$

Thus, $\dot{m}_L\ (h_{f_{173°C}} + 0.295\ h_{fg_{173°C}} - h_{f_{155°C}}) = \dot{m}_G(h_{f_?} - h_{f_{149°C}})$

$$151\ (732.8 + 0.295 \times 2037.7 - 653.8) = 1070\ (h_{f_?} - 627.8)$$

$$h_{f_?} = 723.8 \text{ kJ/kg}$$

The exit temperature is about 171°C.

2. For one pressure tube:

$$\dot{Q}_{PT} = \dot{m} \times (h_{f_{300°C}} - h_{f_{244°C}})$$

$$= 24 \times (1309.23 - 1023.64)$$

$$= 6854.16 \text{ kJ/s}$$

The reactor thermal power output is:

412 x 6854.16 = 2820 MW

PI 25-4 - SELF EVALUATION ANSWER SHEET

1. (a) The effect of too high a pressure in the heat transport system is the possibility of rupture, leading to a loss of coolant accident.

   (b) There are two effects of too low a heat transport pressure:

   (i) The D_2O could reach saturation conditions and boil. This boiling, if it leads to vapor film formation around the fuel, could result in fuel failure and release of fission products to the PHT system.

   (ii) The PHT main circulating pumps may cavitate. The cavitation can result in impairment of flow and loss of fuel cooling, and it can result in damage to the circulating pumps.

2. Pressure control is established in this feed and bleed system by means of a balance in flow between the bleed valves and the feed valves, taking into account the reflux cooling flow.

   The bleed valves tend to lower the PHT pressure by admitting D_2O from the PHT system to the bleed condenser. The bleed condenser pressure is maintained lower than PHT pressure by cooling via the reflux cooling line, and the reflux cooling flow is cooled by the bleed cooler.

   The feed valves tend to raise the PHT pressure by admitting high pressure D_2O from the PHT pressurizing pump outlet to the PHT system.

3. This system uses a pressurizer to control PHT pressure. Raising and lowering pressure is accomplished using the same connecting line from the PHT system to the pressurizer.

   Raising pressure is done using electric immersion heaters in the pressurizer. The heaters raise the temperature and pressure of the D_2O in the pressurizer, and then in the PHT system via the connecting line.

   Lowering pressure is accomplished by removing D_2O vapor from the pressurizer to the bleed condenser using the D_2O vapor control valves. The pressure in the pressurizer drops, and the PHT system pressure drops via the connecting line.

4. *Boiler pressure control is important because boiler* pressure is the variable used to control the match between the reactor heat input to the boiler and the heat output from the boiler as steam flow.

5. The three main heat sinks for the boiler in a CANDU station are: the turbine set, the condenser, and the atmosphere.

6. (a) In the case of maintaining constant boiler pressure, power is increased by first increasing steam flow from the boilers. This would tend to lower the boiler pressure. To maintain it constant, the BPC program causes the reactor power to increase so that heat input matches heat output. Since the boiler pressure is constant so is the boiler temperature. Therefore, increasing power, ie, the amount of heat transferred in the boilers, causes the PHT D_2O average temperature to rise.

   (b) In the case of variable boiler pressure, power is *increased by first increasing the reactor power.* This would tend to raise the boiler pressure. However, the BPC program increases the steam flow from the boilers so that heat output matches the increased heat input. This increase in the steam flow causes the boiler pressure to fall. This results in a corresponding decrease in boiler water temperature so that larger ΔT exists between the PHT D_2O and the boiler water. Thus more heat can be transferred in the boiler while maintaining the PHT D_2O average temperature constant.

PI 25-5 - SELF EVALUATION ANSWER SHEET

1. (a) Heat transfer by conduction involves heat transfer from one molecule to the next through a substance, with no net transfer of mass.

   (b) Heat transfer by natural convection is heat transferred due to fluid movement, which occurs because of density differences established as heat is transferred.

   (c) Forced convection is heat transfer by fluid movement, which is due to some external means (eg, pumps, fans, blowers).

   (d) Heat transfer by radiation involves the emission of electromagnetic waves (mainly infrared light) from a high temperature object. The energy emitted transfers heat from the object.

2. The factors affecting each mechanism are as shown:

   (a) Conduction:

   (i) thermal conductivity of the conducting substance
   (ii) surface area of the conducting substance
   (iii) temperature difference across the conducting substance
   (iv) thickness of the conducting substance.

   (b) Natural convection:

   (i) surface area in contact with the fluid
   (ii) temperature difference between the surface and the fluid
   (iii) heat transfer coefficient of the system.

   (c) Forced convection:

   (i) surface area in contact with the fluid
   (ii) temperature difference between the surface and the fluid
   (iii) heat transfer coefficient of the system.

(d) Radiation:

(i) surface area of the emitting object

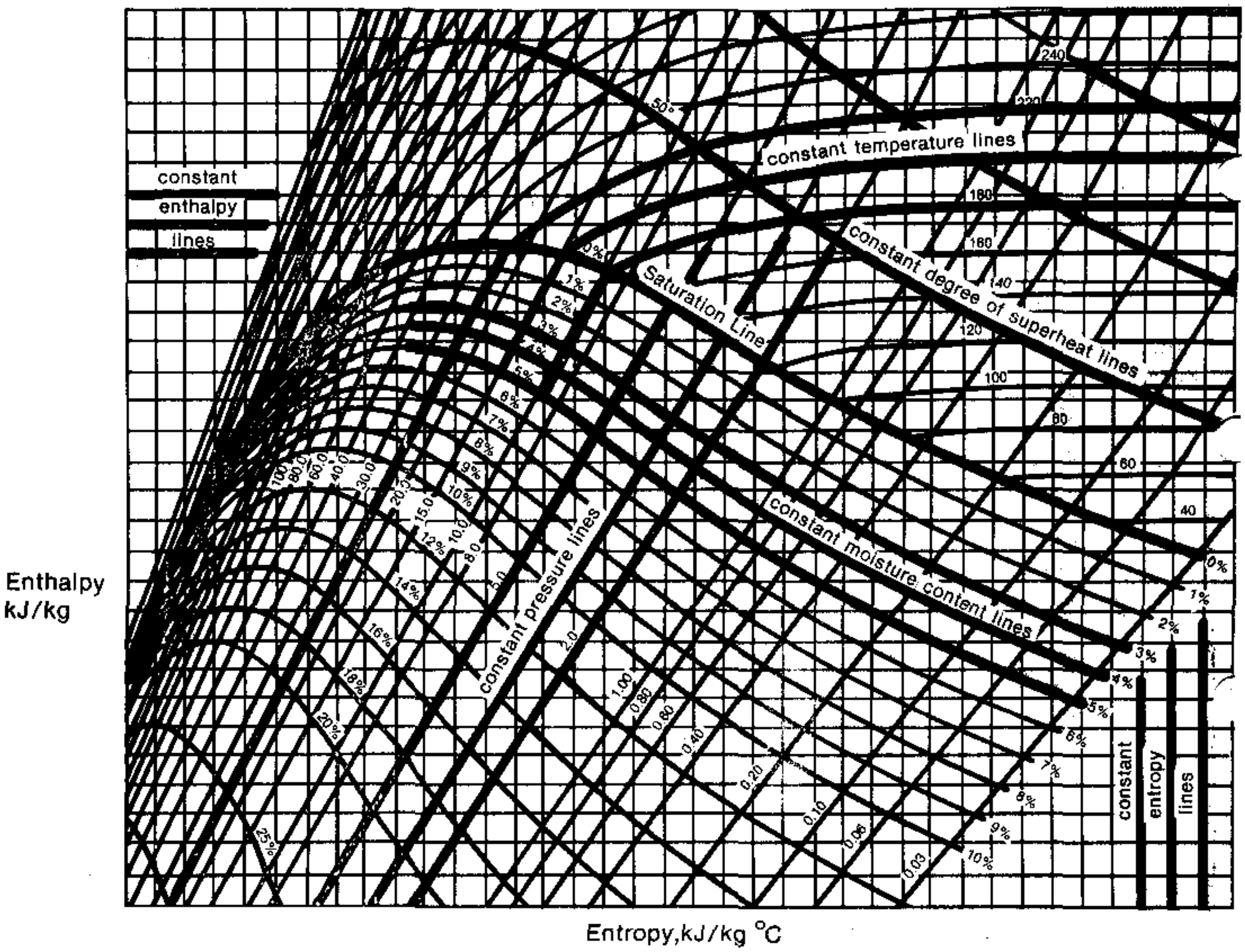
(ii) the difference between the fourth power of the absolute temperature of the object and the fourth power of the absolute temperature of the surroundings

(iii) emissivity of the surface of the object.

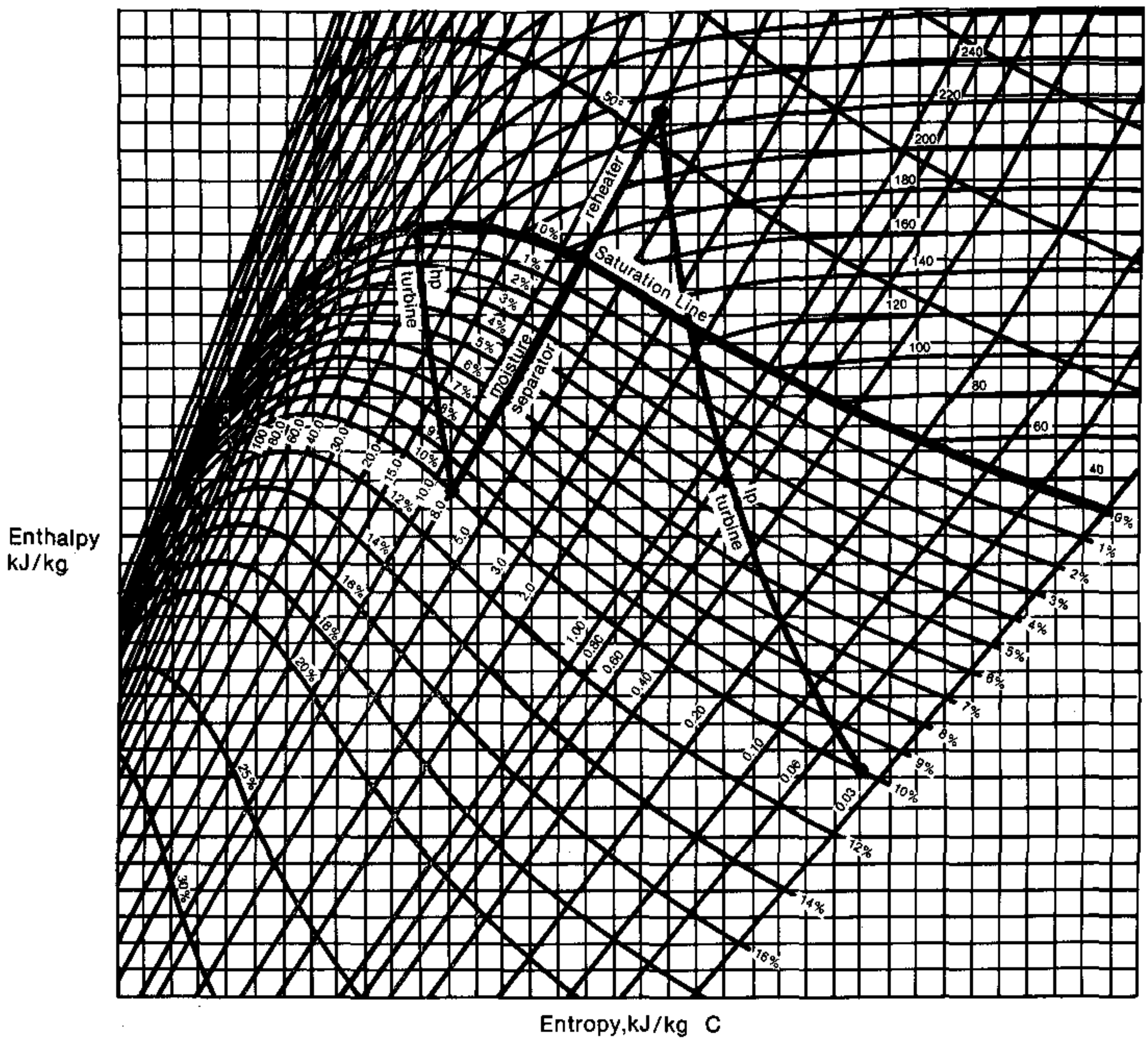
3. Discuss your answers with the course manager before you proceed.

PI 25-6 - SELF EVALUATION ANSWER SHEET

1. Your diagram should be similar to the one shown:



2. Your answer should be similar to the one below:



3. The steam entering the moisture separator is wet. Its enthalpy is in fact a weighted average of saturated liquid and saturated steam enthalpies. The separator removes the liquid portion of the wet steam; thus the enthalpy (ie, heat content per kg of fluid) will increase. The flow of fluid going to the LP turbine has decreased at the same time.

Reheating uses live steam (at 250-260°C) from the main steam line to heat the steam flowing to the LP turbine. Thus, the steam enthalpy is increased.

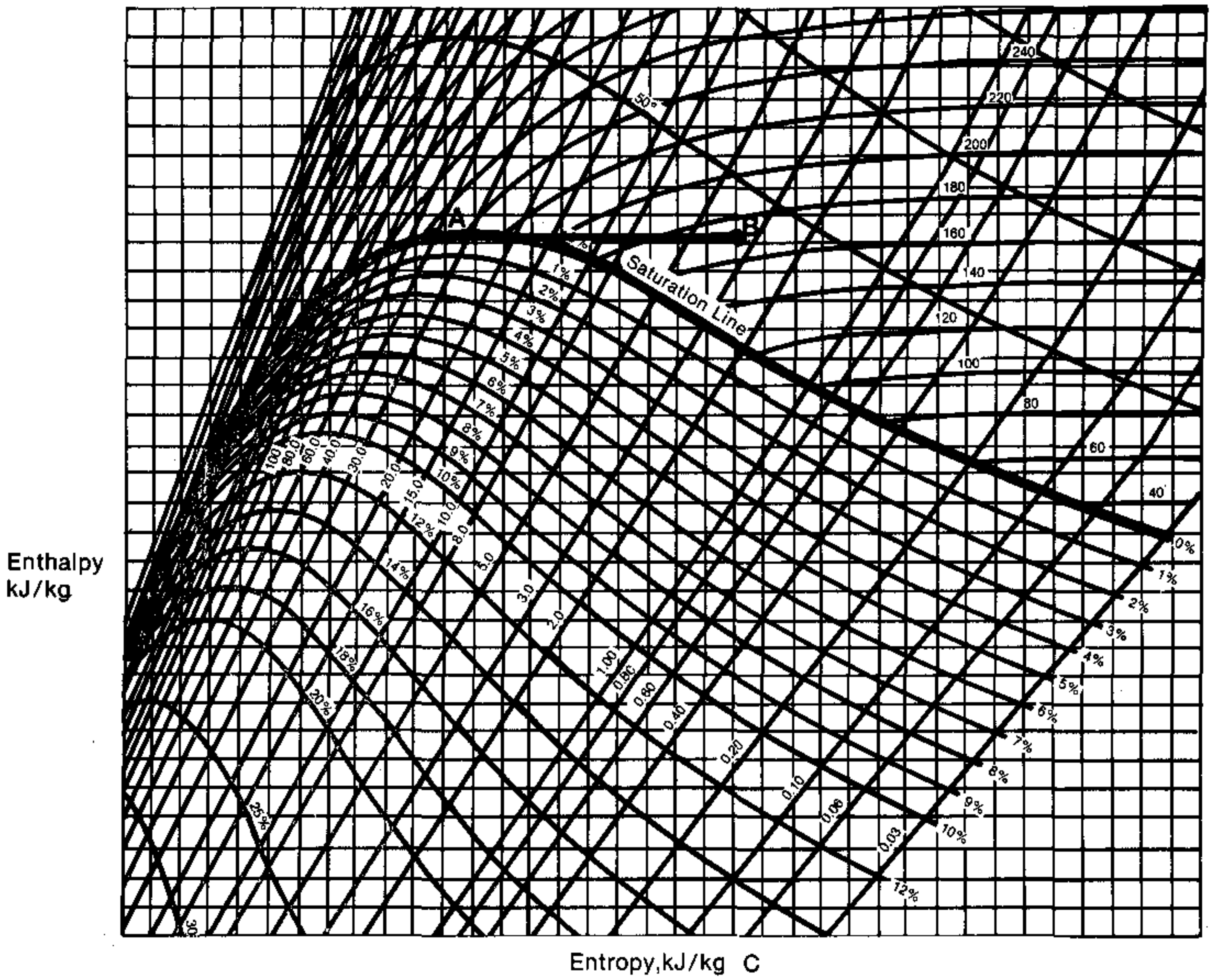
4. Moisture separation reduces the moisture content of the steam exhausted from the HP turbine from about 10% to nearly zero. As the steam at the LP turbine inlet has less moisture, then the moisture content of the steam at the LP turbine outlet can be reduced.

   Reheating allows the LP turbine to be supplied with superheated steam so that production of moisture can be postponed until the latter portion of the LP turbine. Therefore, the moisture content of the steam at the turbine outlet is reduced more than in the case of using moisture separation alone.

5. Throttling is a process which occurs when a compressible fluid (eg, steam) flows through a valve or a pipeline from one pressure to a lower pressure. During this process no mechanical work is done and practically no heat is lost, so that the enthalpy of the fluid remains essentially constant.

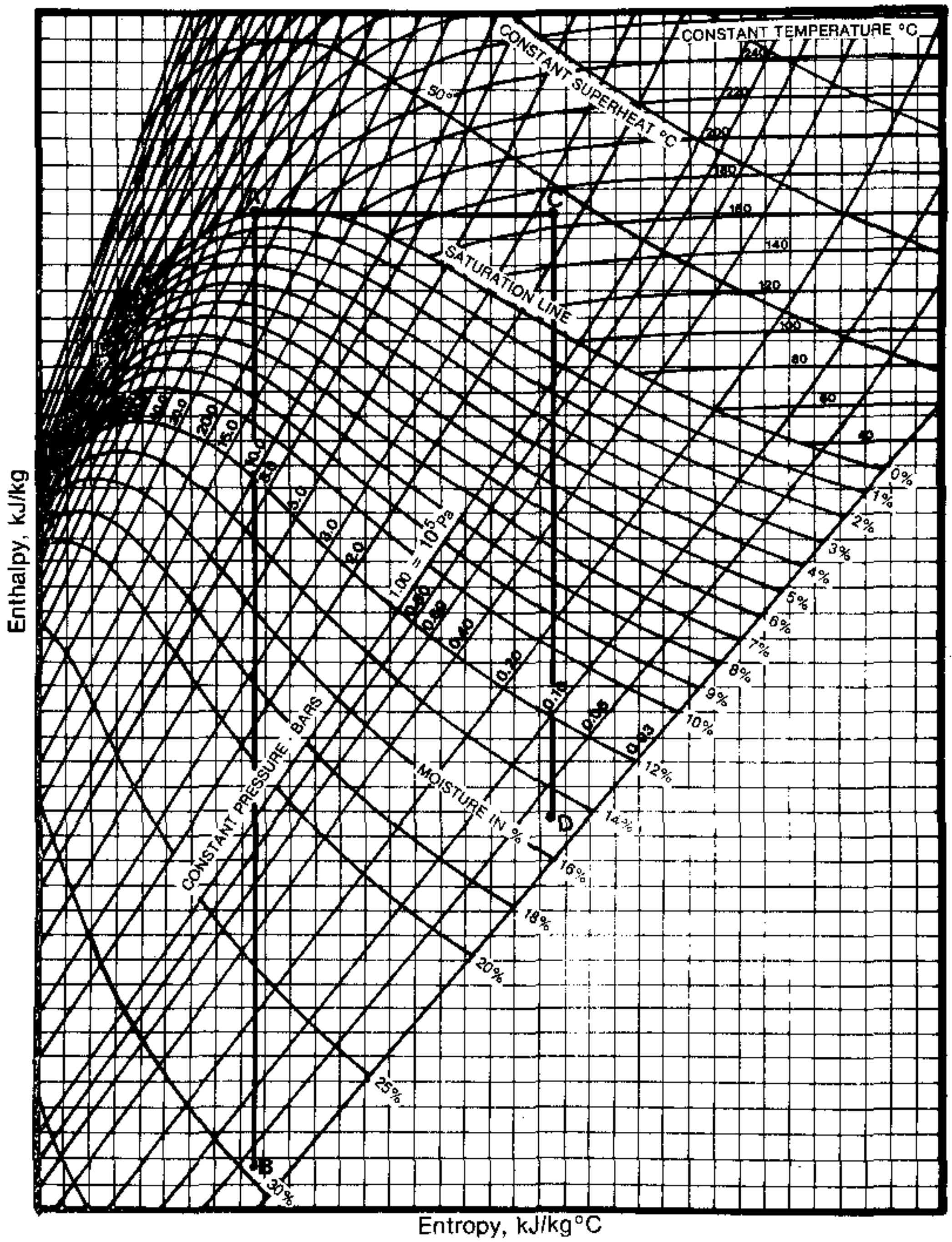
Your answer should be similar to the one below:

(a)



As the diagram shows, both the pressure and temperature of the steam are reduced, and it becomes superheated (zero moisture content).

(b)



As the diagram shows, throttling of the steam supplied to the turbine reduces the amount of heat which can be converted into mechanical work by the turbine ($h_A - h_B > h_C - h_D$).

PI 25-7 - SELF EVALUATION ANSWER SHEET

1. (a) Efficiency - output divided by input, often expressed as a percentage.

   (b) Thermal efficiency - net work output of a system divided by total heat input to the system, often expressed as a percentage.

2. The net work output here is 796 - 6 = 790 MW.

   The heat input is 2450 MW.

   The thermal efficiency is (790 ÷ 2450) x 100 = 32.2%.

3. (a) As boiler pressure (ie, steam pressure) is increased, so is the steam temperature. As this occurs, the ratio of work available to heat input increases, and the thermal efficiency increases.

   (b) The main limitation is a maximum steam temperature (about 260°C) in the boilers, which is imposed by fuel and fuel sheath considerations.

4. (a) As condenser pressure (and temperature) are lowered, the work produced in the turbine increases. The ratio of net work output to total heat input, ie, the thermal efficiency of the cycle, thus increases.

   (b) The limitations on the efficiency improvement in (a) are:

   (i) the temperature of the cooling water is the same as lake temperature.

   (ii) the moisture content in the LP turbine has a limit (about 10-12%).

5. (a) Superheated steam produced in boilers increases the ratio of available work to heat input, and thus also the thermal cycle efficiency.

   (b) The main limitation is the steam temperature (about 250-260°C) imposed by fuel and fuel sheath considerations.

6. (a) (i) Reheating provides superheated steam to the LP turbine, and the work available to heat input ratio per kg of steam flow in the turbine increases.

(ii) Use of extraction steam for feedheating allows recovery of the heat contained in the steam (which would be rejected to the lake if the steam flowed through the turbine) at the expense of some loss of work output. The ratio of work produced to heat input (ie, the thermal efficiency of the cycle) is increased.

(b) (i) Live steam temperature, which in turn has a 250-260°C limit, is the main limitation on reheating.

(ii) The limitation on feedheating is economic. As the number of feedheaters increases, there is a point at which the cost of equipment outweighs the gain in efficiency.

(c) (i) Two practical benefits of reheating are a reduction of moisture content in the LP turbine and a smaller steam flow (and thus smaller equipment) needed to produce a given power.

(ii) Two practical benefits of using extraction steam for feedheating are a reduction of moisture content in the turbine and a reduction in turbine size due to smaller flow through the outlet portion of the turbine.

7. (a) Moisture separation allows less work loss due to moisture droplets in the LP turbine. This allows the turbine to produce more work for the same heat input, and the thermal efficiency increases.

(b) The practical benefit of moisture separation is that a lower condenser pressure can be used without exceeding exhaust steam moisture limits.