COVENANT UNIVERSITY NIGERIA

TUTORIAL KIT OMEGA SEMESTER

PROGRAMME: CHEMICAL ENGINEERING

COURSE: CHE 320

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CHE325: CHEMICAL ENGINEERING THERMODYNAMICS I

Contributors: Dr. Udonne J, Engr. Ayoola A.

1. What are the two statements of the second law of thermodynamics?

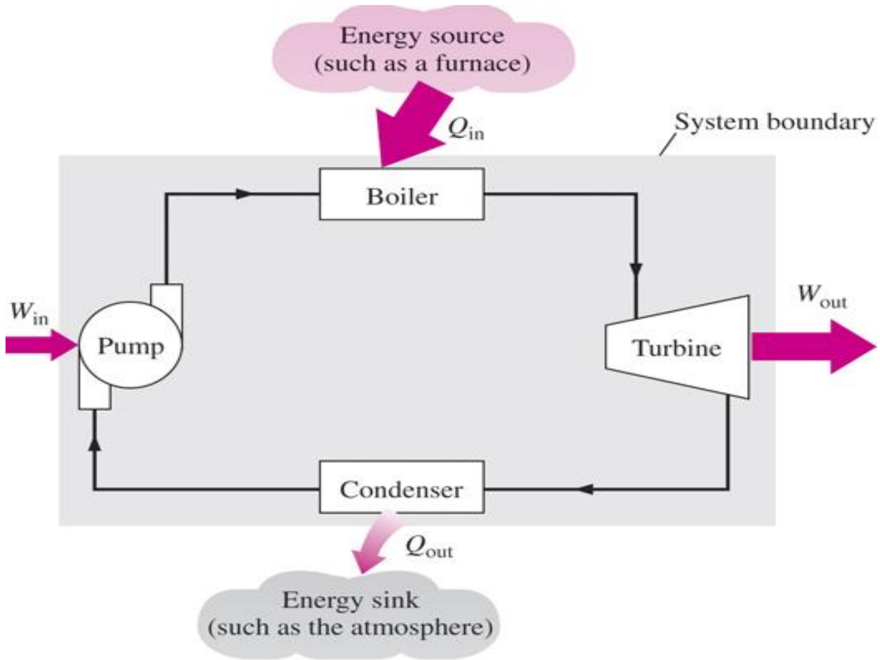
- No apparatus can operate in such a way that its only effect (in system and surroundings) is *to convert heat absorbed by a system completely into work done by the system.*

- No process is possible solely in the transfer of heat *from one temperature level to a higher one.*

2. Define the following terms:
   a) Heat Reservour
   b) Work Reservour
   c) Working fluid
   d) Heat Engine
   e) Thermodynamic cycle

   Support your answers with diagrams, where necessary.

3. State the mode of operation of a typical heat engine. Support your answer with a well labelled diagram



Operation of A Heat Engine

- Heat is supplied from a boiler to water that gets converted to steam at reversible isothermal expansion.
- High pressure steam performs work on the turbine by rotating it, the steam turns to vapour due to reversible adiabatic expansion experienced.
- The vapour loses heat to the surroundings through condenser
- Work is done on the water by pumping it, under reversible adiabatic compression, to the boiler.

4. State the statements made by Kelvin-Planck,Clausius and Kelvin on the second law of thermodynamics.
5. State the desire objective of
    a) A Heat Engine
    b) A Heat Pump
    c) A Refrigerator

- Objective of Heat Engine is to convert heat to work.

- Objective of Heat Pump is to maintain a heated space at a high temperature, by absorbing heat from a low temperature source.

- The objective of refrigerator is to remove heat from the refrigerated space

6. A steam power plant with a power output of 150 MW consumes coal at a rate of 60 tons/h. If the heating value of the coal is 30,000 kJ/kg, determine the overall efficiency of this plant.
7. The data listed below are claimed for a power cycle operating between reservours at 527 °C and 27 °C. Determine whether any principles of thermodynamics would be violated if
   Q_H = 700 kJ, W_{cycle} = 400 kJ and Q_C = 300 kJ.

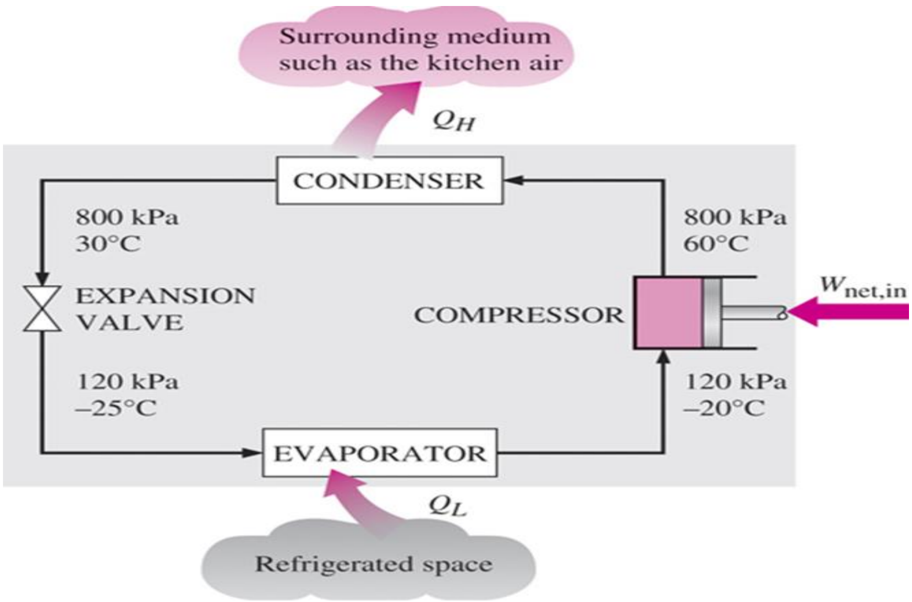
8. The operations of Carnot cycle of both refrigerator and heat pump are the same. Use relevant diagram to explain the operation.
9. State 5 importance of the second law of thermodynamics
    - Prediction of process direction.
    - Establishment of equilibrium conditions.
    - Determination of the best *theoretical* performance of cycles, engines and other devices.
    - Quantitative evaluation of factors that preclude the attainment of the best theoretical performance level.
    - Determination of properties such as U and H in terms of more readily experimentally determined properties.

10. A heat pump is to maintain a house at 20°C when the outside air is at −25°C. It is determined that 1800 kJ is required each minute to accomplish this. Calculate the minimum power required.

11. Show that COP_{HP} -COP_R = 1

12. A heat pump is to provide 2000 kJ/h to a house maintained at 20°C. If it is −20°C outside, what is the minimum power requirement?

13. State the mode of operation of a typical refrigerator. Support your answer with a well labelled diagram
    a) The refrigerant enters the compressor as vapour and compressed to condenser pressure.
    b) It condenses as it flow through the coils of the condenser by rejecting heat to the surrounding medium.
    c) Its pressure and temperature drop drastically as it expands in capillary tube.
    d) It evaporates in evaporator by absorbing heat from the refrigerated space.



14. Deduce the entropy change of an ideal gas.

15. An automobile engine consumes fuel at a rate of 28 L/h and delivers 60 kW of power to the wheels. If the fuel has a heating value of 44,000 kJ/kg and a density of 0.8 g/cm³, determine the efficiency of the engine.

Volumetric flow rate = $\frac{28\ L}{h}$

$= \frac{28\ L}{h}$ x $\frac{0.001 m^3}{1L}$ X $\frac{1\ h}{(60\ X\ 60)s}$= 7.78 X 10^{-6} $\frac{m^3}{s}$

Density = $\frac{0.8\ g}{cm^3}$

$= \frac{0.8\ g}{cm^3}$ x $\frac{1000 cm^3}{0.001 m^3}$ X $\frac{1\ kg}{1000 g}$= $800\frac{kg}{m^3}$

Mass flow rate = Volumetric flow rate X Density

= 7.78 X 10^{-6} $\frac{m^3}{s}$ X 800 $\frac{kg}{m^3}$

= $0.006224\frac{kg}{s}$

$\eta_{HE} = \frac{|W|}{|Q_H|} = \frac{60}{(40,000\ X\ 0.006224)}$ = 0.22

16. 1 kg of air as an ideal gas executes a Carnot power cycle having a thermal efficiency of 60 %. The heat transfer to the air during the isothermal expansion is 40 kJ. At the end of the isothermal expansion, the pressure is 5.6 bar and the volume is 0.3 m³. Determine
   a) Sketch the cycle on p-v coordinates.
   b) The maximum and minimum temperatures for the cycle, in K.
   c) The pressure and volume at the beginning of the isothermalexpansion in bar and m³,

respectively.

d) The work and heat transfer for each of the four processes, in kJ.

Given: $U_{@585K}$ = 423.7 kJ/kg and $U_{@234K}$ = 167.0 kJ/kg,
Molar mass of air = 28.97

17. State two corollaries of the second law of thermodynamics

    a) The coefficient of performance of an irreversible refrigerator cycle is always less than the coefficient of performance of a reversible refrigerator cycle when each operates between the same two thermal reservours.

    b) All reversible refrigerator cycles operating between the same two thermal reservours have the same coefficient of performance.

18. An inventor claims to have developed a device that undergoes a thermodynamic cycle while communicating thermally with two reservouirs. The system receives energy Q_C from the cold reservoir and discharges energy Q_H to the hot reservouirwhile delivering a net amount of work to its surroundings.There are no other energy transfers between the device and its surroundings. Using the second law of thermodynamics, evaluate the inventor's claim.

19. State one limitation of the first law of thermodynamics

    - First law fails to address both the direction of the process and the extent of change of energy from one form to another.

20. A power cycle operates between a reservoir at temperature *T* and a lower-temperature reservoir at 280 K. At steady state, the cycle develops 40 kW of power while rejecting 1000 kJ/min of energy by heat transfer to the cold reservoir. Determine the minimum theoretical value for *T*, in K.

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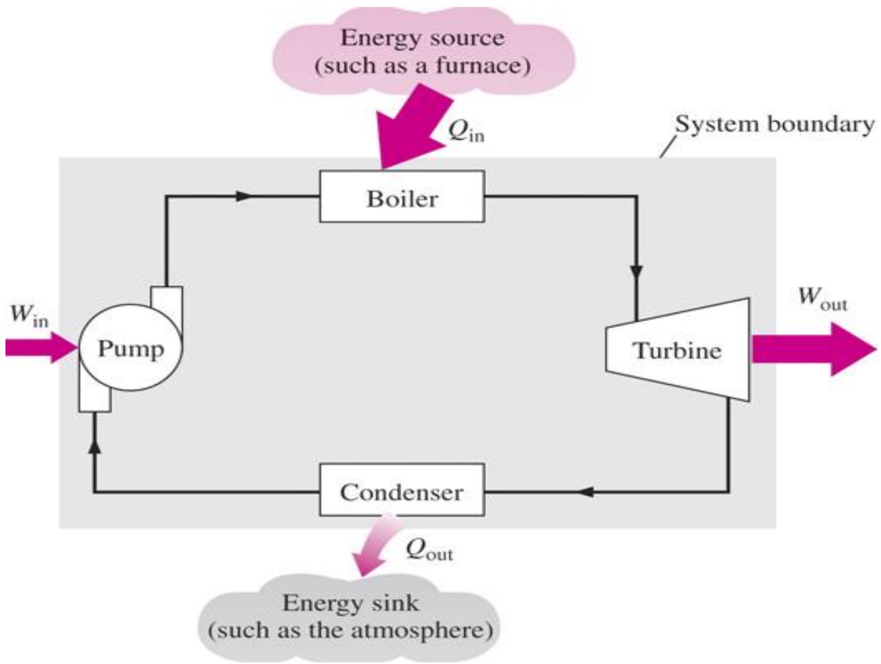
Q1.

(i) No apparatus can operate in such a way that its only effect (in system and surroundings) is *to convert heat absorbed by a system completely into work done by the system.*

(ii) No process is possible solely in the transfer of heat *from one temperature level to a higher one.*

Q3



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Q5.

- Objective of Heat Engine is to convert heat to work.
- Objective of Heat Pump is to maintain a heated space at a high temperature, by absorbing heat from a low temperature source.
- The objective of refrigerator is to remove heat from the refrigerated space

Q7.

T_H = 527 ºC = (527 + 273) K = 800 K
T_C = 27 ºC = (27 + 273) K = 300 K
Principles of thermodynamics would be violated once the efficiency is greater than that of Carnot engine or conservation of energy principle is violated

a) Q_H = 700 kJ, W_{cycle} = 400 kJ, Q_C = 300 kJ

$\eta_{carnot} = 1 - \frac{|T_C|}{|T_H|}$ where

$= 1 - \frac{300}{800} = 0.625$

$\eta_{HE} = \frac{|W|}{|Q_H|} = \frac{400}{700} = 0.5714$

Since $\eta_{carnot} > \eta_{HE}$, principles of thermodynamics are not violated.

Q9. 5 importance of the second law of thermodynamics:

- Prediction of process direction.
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Q11.

$COP_{HP} = \frac{\text{Desired Output}}{\text{Required Input}} = \frac{Q_H}{W_{net,in}}$

$= \frac{Q_H}{Q_H - Q_L} = \frac{1}{1 - \frac{Q_L}{Q_H}}$ ……………………..1

$COP_R = \frac{\text{Desired Output}}{\text{Required Input}} = \frac{Q_L}{W_{net,in}}$

$= \frac{Q_L}{Q_H - Q_L} = \frac{1}{\frac{Q_H}{Q_L} - 1}$ ……………………..2

From Equation 1and Equation 2,

$COP_{HP} - COP_R$

$= \frac{Q_H}{W_{net,in}} - \frac{Q_L}{W_{net,in}}$

$= \frac{Q_H - Q_L}{W_{net,in}}$ since $W_{net,in} = Q_H - Q_L$

Hence

$COP_{HP} - COP_R = \frac{W_{net,in}}{W_{net,in}} = 1$

So

$\mathbf{COP_{HP} - COP_R = 1}$

Q13. The mode of operation of a typical refrigerator:

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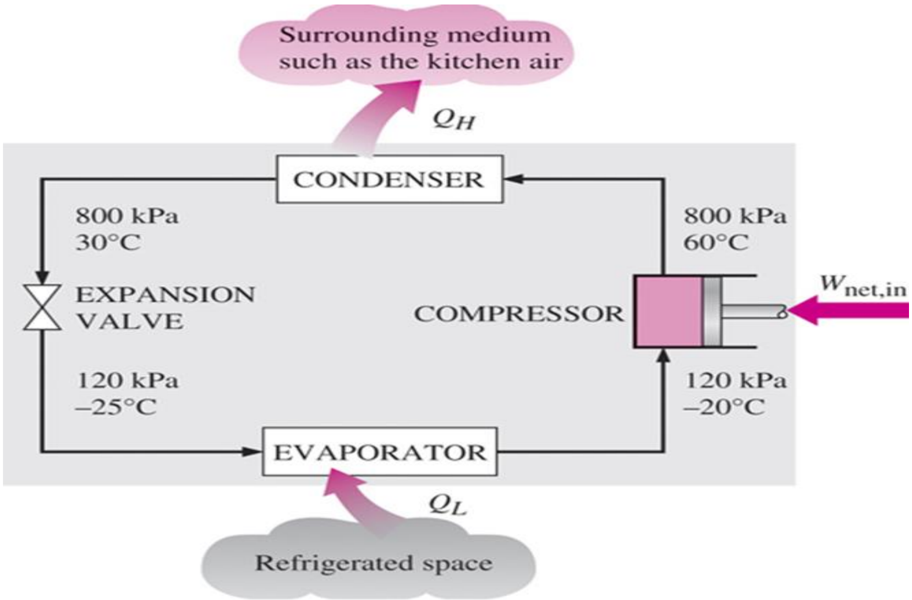

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Q19. One limitation of the first law of thermodynamics

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