Chemical Engineering (Thermodynamics I) (UCH305)

Dr. Neetu Singh
Associate Professor
Department of Chemical Engineering

Thapar Institute of Engineering & Technology
(Deemed to be University)
Bhadson Road, Patiala, Punjab, Pin-147004
Contact No. : +91-175-2393201
Email : info@thapar.edu

THAPAR INSTITUTE
OF ENGINEERING & TECHNOLOGY
(Deemed to be University)

Lecture 19

Refrigerators and Heat pumps

Refrigerators and Heat pumps

- In heat engines, heat is transferred in the direction of decreasing temperature, that is, from high-temperature mediums to low temperature ones.
- This heat transfer process occurs in nature without requiring any devices.
- The reverse process, however, cannot occur by itself.
- For the transfer of heat from a low-temperature medium to a high-temperature, one requires special devices (Compressors) called ***refrigerators*****.**

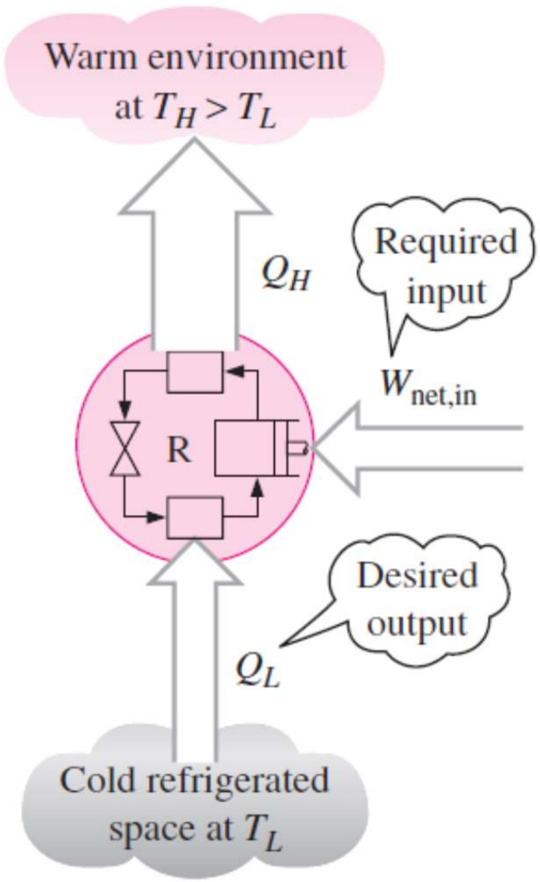
Ton of Refrigeration (TR)

- ***Ton of Refrigeration*** is the ***capacity*** of heat removal from the system.
- Tons of Refrigeration or simply Tons is often used as a general term to indicate the capacity or size of the refrigeration plant.
- Ton of Refrigeration (abbreviated as TR) is an important historical unit of refrigeration capacity.
- Originally ***1 TR*** was defined as the ***rate of heat transfer*** required to ***make*** **1 short ton (2000 lbs) of ice per day** from water at ***0^oC***.
- American Society of Heating, Refrigerating and Air-conditioning Engineers (***ASHRAE***) defines ***1 TR*** as equivalent to a refrigeration capacity of ***3.51685 kW*** or ***3023.95 kcal/h***.
- Thus 1 TR air conditioner has a refrigeration capacity of 3516.85 W at the prescribed temperatures.
- 1 ***ton refrigeration*** = 200 Btu/min = ***3.517 kJ/s*** = 3.517 kW = ***4.713 HP***
- ***1 TR = 211 kJ/min***.

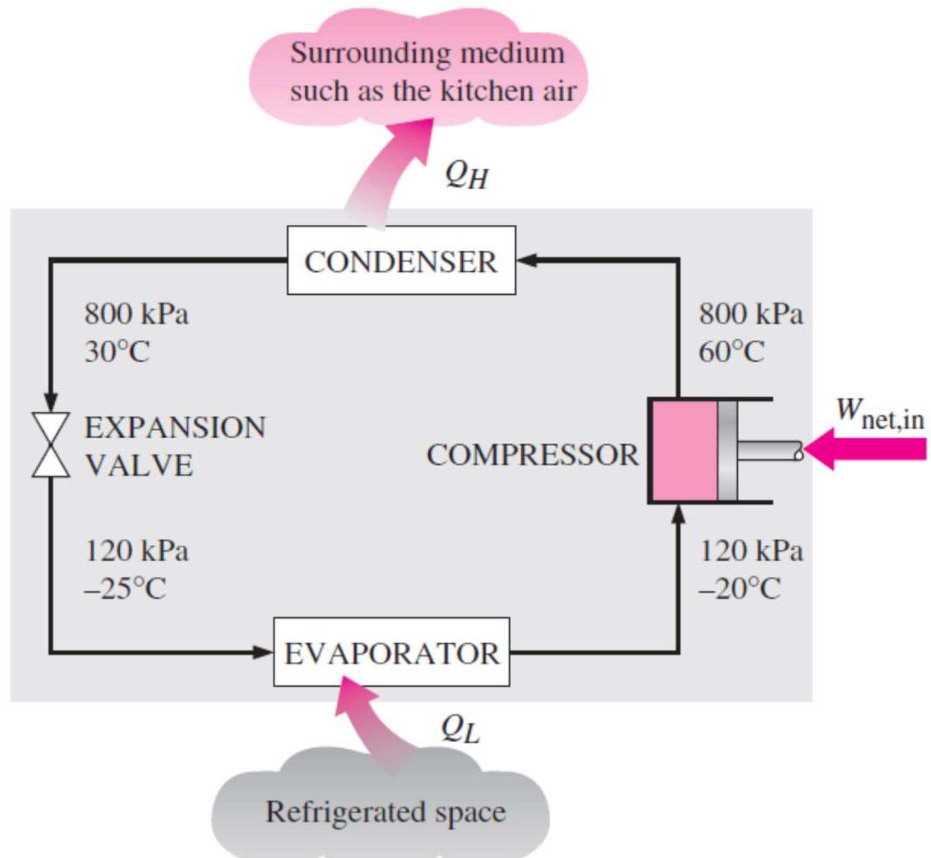
- Refrigerators, like heat engines, are cyclic devices.

- The working fluid used in the refrigeration cycle is called a ***refrigerant*****, viz.,**
  - R22, R-32, R123, R124, R401A, R401B, R402A, R403B, R408A, R409A, R414B, R416A, etc.

- The most frequently used refrigeration cycle is the *vapor-compression refrigeration cycle*, which involves four main components:
  - a compressor,
  - a condenser,
  - an expansion valve, and
  - an evaporator



The objective of a refrigerator is to remove Q_L from the cooled space.



Basic components of a refrigeration system and typical operating conditions.

Refrigeration process

- The refrigerant enters the compressor as a **vapor** and is compressed to the condenser pressure.

- It leaves the **compressor** at a relatively high temperature and cools down and condenses as it flows through the coils of the condenser by rejecting heat to the surrounding medium.

- It then enters a capillary tube where its ***pressure and temperature drop*** drastically due to the throttling effect.

- The low-temperature refrigerant then enters the evaporator, where it evaporates by absorbing heat from the refrigerated space.

- The cycle is completed as the refrigerant leaves the evaporator and re-enters the compressor.

Household refrigerator

- In a household refrigerator,
  - the freezer compartment where heat is absorbed by the refrigerant serves as the evaporator, and
  - the coils usually behind the refrigerator where heat is dissipated to the kitchen air serve as the condenser.

- Here
  - Q_L is the magnitude of the heat removed from the refrigerated space at temperature T_L,
  - Q_H is the magnitude of the heat rejected to the warm environment at temperature T_H, and
  - $W_{\text{net,in}}$ is the net work input to the refrigerator.
  - Q_L and Q_H represent magnitudes and thus are positive quantities

Coefficient of Performance (COP)

- The *efficiency* of a refrigerator is expressed in terms of the **coefficient of performance** (COP), denoted by COP_R.

- The objective of a refrigerator is to remove heat (Q_L) from the refrigerated space.

- To accomplish this objective, it requires a work input of $W_{net,in}$.

- Then the COP of a refrigerator can be expressed as:

$$\boxed{COP_R = \frac{Desired\ output}{Required\ input} = \frac{Q_L}{W_{net,in}}}$$

- This **relation** can also be expressed in rate form by replacing Q_L by $\dot{Q}_L$ and W_{in} by $\dot{W}_{\text{in}}$.

- The conservation of energy principle for a cyclic device requires that

$$W_{\text{in}} = Q_H - Q_L \quad \text{(kJ)}$$

- Then the COP_R relation becomes:

$$COP_R = \frac{Q_L}{W_{in}} = \frac{Q_L}{(Q_H - Q_L)} = \frac{1}{\left(\frac{Q_H}{Q_L} - 1\right)} = \frac{1}{(Q_H / Q_L - 1)}$$

$$COP_R = \frac{T_L}{(T_H - T_L)} = \frac{1}{(T_H / T_L) - 1}$$

- Most air conditioners have a COP of 2.3 to 3.5.

- Notice that the value of COP_R can be greater than unity.
- That is, the amount of heat removed from the refrigerated space can be greater than the amount of work input.
- This is in contrast to the thermal efficiency, which can never be greater than ***1***.
- In fact, *one reason* for expressing the efficiency of a refrigerator by another term—the coefficient of performance—is the desire to avoid the oddity of having efficiencies greater than unity.

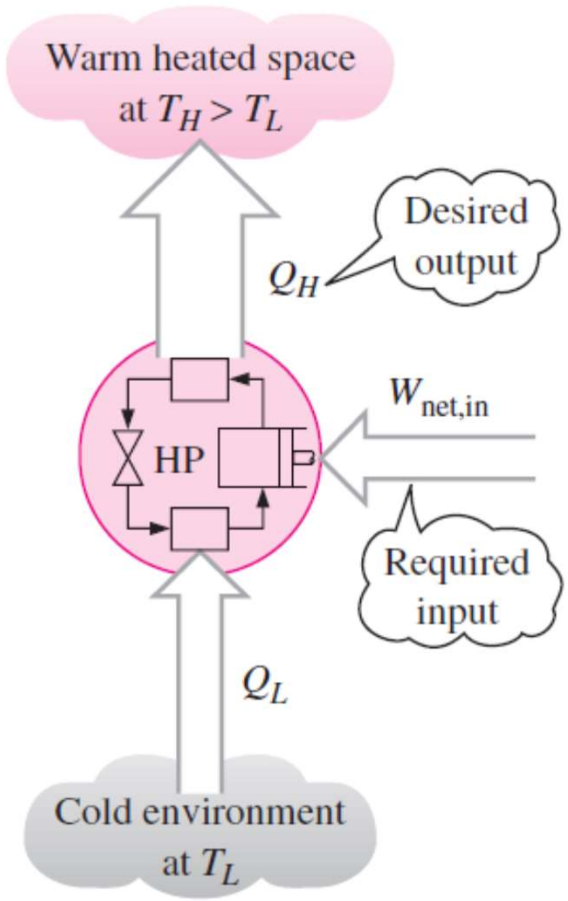
Heat Pumps

- Another device that transfers heat from a low-temperature medium to a high-temperature one is the ***heat pump***.

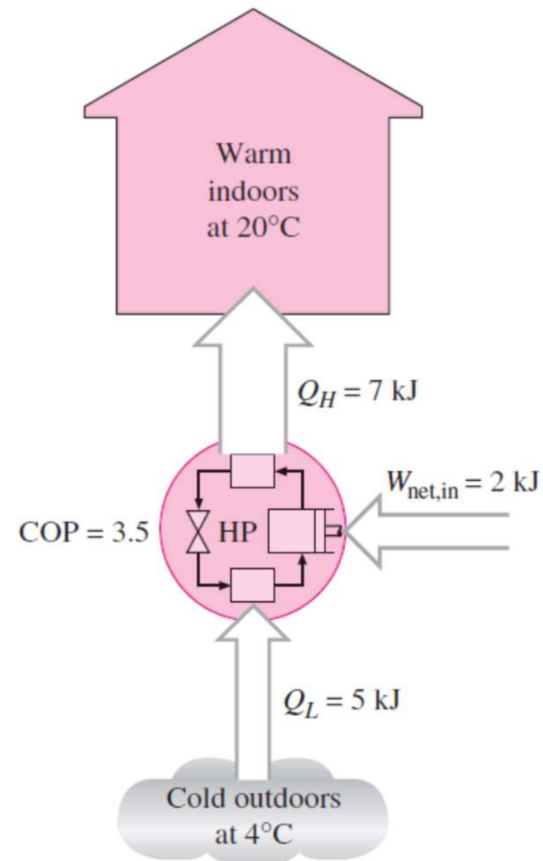
- Refrigerators and heat pumps operate on the same cycle but differ in their objectives.

- The objective of a refrigerator is to maintain the refrigerated space at a low temperature by removing heat from it.

- Discharging this heat to a higher-temperature medium is merely a necessary part of the operation, not the purpose.



The objective of a heat pump is to supply heat *QH* into the warmer space.



The work supplied to a heat pump is used to extract energy from the cold outdoors and carry it into the warm indoors.

- The objective of a heat pump, however, is to maintain a heated space at a high temperature.

- This is accomplished by absorbing heat from a low-temperature source, such as:
  - well water, or
  - cold outside air in winter, and
    - * supplying this heat to the high-temperature medium such as a house.

Refrigerator – to – Heat pump

- An ordinary refrigerator that is placed in the window of a house
- With its door open to the cold outside air in winter
  - will function as a heat pump
- since it will try to cool the outside by absorbing heat from it and
  - rejecting this heat into the house through the coils behind it.

Coefficient of performance of Heat pump (COP_{HP})

- The measure of performance of a heat pump is also expressed in terms of the **coefficient of performance** COP_{HP}, defined as:

$$COP_{HP} = \frac{Desired\ output}{Required\ input} = \frac{Q_H}{W_{net,in}}$$

$$COP_{HP} = \frac{Q_H}{(Q_H - Q_L)} = \frac{1}{(1 - Q_L / Q_H)} = \frac{1}{\left(1 - \frac{Q_L}{Q_H}\right)}$$

$$COP_{HP} = \frac{T_H}{(T_H - T_L)}$$

- The relation between coefficient of performances of ***heat pump*** and ***refrigerator*** is: $COP_{HP} = COP_R + 1$

- Most heat pumps in operation today have a seasonally averaged COP of 2 to 3.

$COP_{HP} = (COP_R + 1)$?

$$COP_R + 1 = \frac{T_L}{T_H - T_L} + 1$$
$$= \frac{T_L + T_H - T_L}{T_H - T_L}$$
$$= \frac{T_H}{T_H - T_L}$$
$$= COP_{HP}$$

$\because$

$$COP_R = \frac{T_L}{T_H - T_L}, \quad and$$
$$COP_{HP} = \frac{T_H}{T_H - T_L}$$

Therefore,

$COP_{HP} = (COP_R + 1)$

Comparison of heat engine, refrigerator and heat pump

Sl. No	Item description	Desired output	Required input	Efficiency / COP
1	Heat Engine	Work output, W_{out}	Energy input, Q_H or T_H	η = Desired output ÷ Required input $\eta = Work_{out}/Energy_{input}$ $\eta = W_{out}/Q_H$ $\eta = (Q_H - Q_L)/Q_H$ $\eta = 1 - (Q_L/Q_H)$ $\eta = (T_H - T_L)/T_H$ $\eta = 1 - (T_L/T_H)$
2	Refrigeration	Energy output, Q_L or T_L	Work input, W_{in}	COP = Desired output ÷ Required input $COP = Q_L/W_{in}$ $COP = Q_L/(Q_H - Q_L)$ $COP = T_L/(T_H - T_L)$
3	Heat pump	Energy output, Q_H or T_H	Work input, W_{in}	COP = Desired output ÷ Required input $COP = Q_H/W_{in}$ $COP = Q_H/(Q_H - Q_L)$ $COP = T_H/(T_H - T_L)$

Perpetual-Motion Machines (PPM2)

- A process cannot take place unless it satisfies both the first and second laws of thermodynamics.

- Any device that violates either law is called a **perpetual-motion machine.**

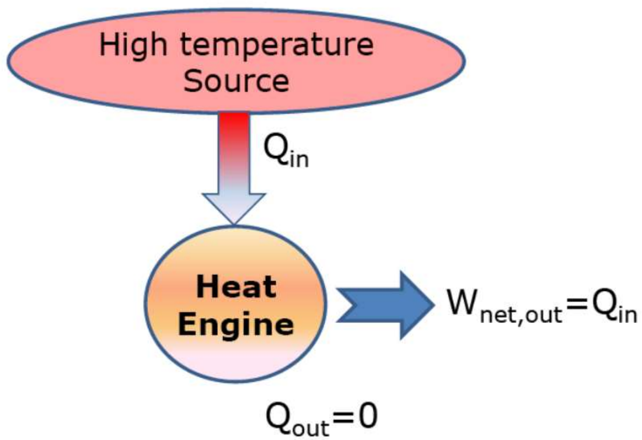
- A device that ***violates*** the first law of thermodynamics is called a **perpetual-motion machine of the first kind** (PMM1).

- A device that ***violates*** the second law of thermodynamics is called a **perpetual-motion machine of the second kind** (PMM2).

- Despite numerous attempts, no perpetual-motion machine is known to have worked.

- But this has not stopped inventors from trying to create new **perpetual-motion machines**.

Perpetual-motion machine of the second kind (PMM2)



Any device that violates the second law is called a perpetual-motion machine of the second kind (PMM2).

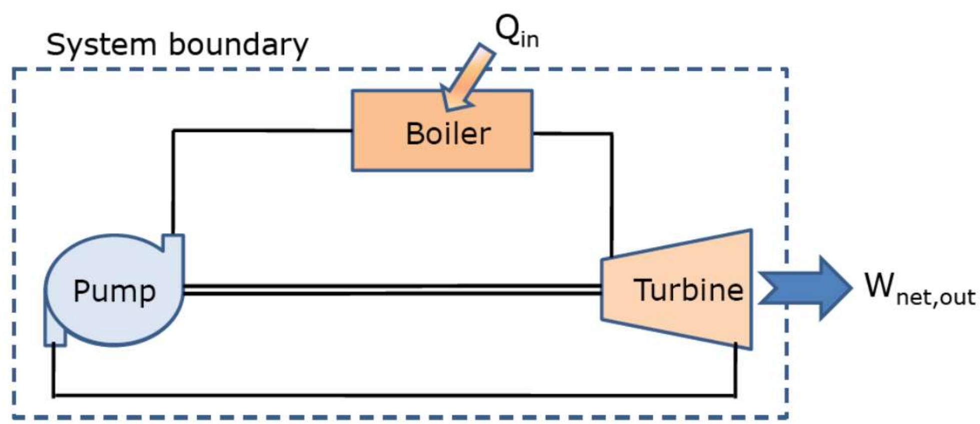
Such a device will:

Either generate work by exchanging heat with a single reservoir,

Or transfer heat from a low temperature reservoir to a higher temperature one without any work input.

In a heat engine, it produces net work output by exchanging heat with only one reservoir, it is PMM2

A violation of the Kelvin-Planck statement as there is no Q_{out}, which means η_{th}=100%.



References

1. *Rao, Y.V.C., Thermodynamics, Universities Press (2004).*
2. *Smith J. M. and Van Ness H. C., Chemical Engineering Thermodynamics, Tata McGraw-Hill (2007).*
3. *Nag, P.K., Engineering Thermodynamics, Tata McGraw Hill (2008) 3rd ed.*
4. *Cengel, Y. A. and Boles, M., Thermodynamics: An Engineeing Approach, Tata McGraw Hill (2008).*

Special Thanks to Professor D. Gangacharyulu.

Thank you for your Patience