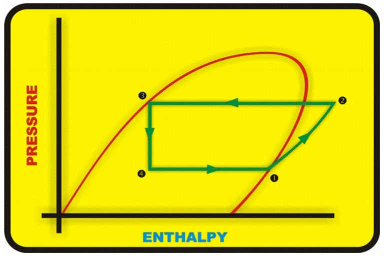
HVAC SYSTEMS AND DESIGNS

INTRODUCTION/ REFRIGERATION REVIEW



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June 9, 2015

TOPIC OBJECTIVES

- Learn the TIP Mission and Vision
- Know the TIP graduate attributes
- Know the Program Educational Objectives and Course Outcomes
- Know the course description
- Familiarize with the student outcomes
- Know the course outcomes
- Review on Refrigeration Systems

The TIP Mission

- The Technological Institute of the Philippines is committed
  - to bring the blessings of higher education within the reach of Filipinos
  - to maintain the highest standard of instruction and to constantly redefine the meaning of academic life, and
  - to transform students into graduates with full competence in their fields of study and who also possesses:

The TIP Mission *cont'd*

- **Filipino Values**

  The Filipino values of honesty and integrity, service to others, the importance of family, frugality, resilience in the face of adversity , and the willingness to surmount difficulties in order to succeed and excel.

- **Industry-desired Values**

  The industry-desired values of positive work attitude, good communication skills, proficiency in computers and in the software that pertain to their fields of study, and the openness to keep on learning to reinvent themselves.

- **Global Citizen Values**

  The global values of respect for cultural diversity, care for the environment and the desire to contribute to the general welfare of society.

The TIP Vision

- In the year 2012, the school's 50th anniversary, TIP envisions itself
  - As the leading school in the fields of Engineering and Information and Communication Technology (ICT) and in all other academic offerings;
  - As a CHED Centre of Excellence or Centre of Development in at least three Engineering programs;
  - As a school steeped in research and community service;
  - As a school that is managed efficiently with computerized operations capable of having fast access to accurate information in order to respond to an ever-changing environment to ensure financial viability; and

The TIP Vision *cont'd*

- As a school with:
  - Level III Accredited Status for 75% of its programs
  - Total Quality Management for all aspects of operations including ISO Certifications in the provision of all its academics
  - The best work environment for its teaching and non-teaching employees, and
  - Strategic alliances with other schools and industry

TIP Graduate Attributes

TIP Graduate Attributes	Institutional Intended Learning Outcomes (IILO)
Professional Competence	**Demonstrate** understanding and mastery of the fundamental knowledge and skills required for effective professional practice in the field of specialization.
Critical Thinking and Problem Solving Skills	**Exercise** critical and creative thinking in providing solutions to discipline-related problems.
Communication Skills	**Apply** effective communication skills, both orally and in writing, using the English language.
Life-long Learning	**Utilize** lifelong learning skills in pursuit of personal development and excellence in professional practice.

TIP Graduate Attributes *cont'd*

TIP Graduate Attributes	Institutional Intended Learning Outcomes (IILO)
Social and Ethical Responsibility	**Hold** personal values and beliefs as ethical professional consistent with Filipino family values, industry-desired values and global citizen values.
Productivity	**Contribute** to nation-building and national development through application of new technology.
Interpersonal Skills	**Work** effectively in multi-disciplinary and multicultural teams.

Program Education Objectives (PEOS)

- The Mechanical Engineering program has adopted the following educational objectives.
- Three to five years after graduation, the Mechanical Engineering alumni shall:
  - have advanced their practice or achievement in the field of Mechanical Engineering and/or other endeavours or advocacies supported by their acquired mechanical engineering education;

Program Education Objectives (PEOS) *cont'd*

strive to be globally competitive through

- living by the TIP mission values, pursuing continuing education, and practicing continuous quality improvement in their personal lives; and
- continuously scanning, adopting, and building on the best practices in their field.

Course Description

- AIR CONDITIONING THEORY AND DESIGN. The course deals with Psychrometric properties of air; factors affecting human comfort, air distribution and basic duct design, drying, heating and ventilation; cooling load calculations; complete design of an air conditioning system and its components.
- Textbooks:
  - *Refrigeration and Air Conditioning* by C. P. Arora; Asia.Tata; McGraw-Hill Publications
  - *Refrigeration and Air Conditioning* by H. Sta. Maria, Mandaluyong; National Book Store

Course Objectives

- Provide information on the significance of air conditioning in the industry.
- Enable students to integrate fundamentals of thermal sciences in developing analysis governing HVAC processes.
- Enable students to use a variety of resources such as technical articles, internet, software, etc.
- Develop student skills in defending a design of centralized air conditioning system using internationally accepted standards.

Course Outcomes

By the end of the course, the students will be able to:

- summarize the major milestones in the history of air conditioning and its impact on the manufacturing industry;
- calculate the theoretical ideal gas problems and theoretical thermodynamic properties of moist air in air conditioning systems;
- predict the theoretical energies and mass flow rates of moist air in the psychrometric processes of air conditioning systems.
- calculate the behaviour of moist air as it goes thru the air conditioning equipment.

Course Outcomes *cont'd*

- prepare a cooling load calculation for a centralized air conditioning system using internationally accepted standards and procedures;
- design the various components of air conditioning system using commercially available model or based on internationally accepted standards and calculation procedures;
- test the design components of air conditioning systems based on thermodynamic laws and principles; and
- generalize the proper usage of the safety factor for HVAC system.

Student Outcomes

- Students will be able to:
  - solve complex engineering problems by designing systems, components, or processes to meet specifications with realistic constraints such as economic, environmental, cultural, socials, societal, political, ethical, health and safety, manufacturability, and sustainability in accordance with standards;
  - use the techniques, skills and modern engineering tools necessary for engineering practice in complex engineering activities.

REFRIGERATION REVIEW

What is Refrigeration?

- Refrigeration – The process of absorbing heat where heat is unwanted, and discharging that heat where it is unobjectionable.
- Aside from the mechanical components that produce refrigeration, another very important component is necessary and this is the refrigerant.
- Refrigerant – A chemical substance that has the characteristics of absorbing heat at a low pressure and temperature, and discharging that heat at a higher pressure and temperature.

Heat Engine and Refrigerating Machine

- A <u>system operating in a cycle and producing a net quantity of work from a supply of heat</u> is called a *heat engine* and is represented in Fig. 1 below.

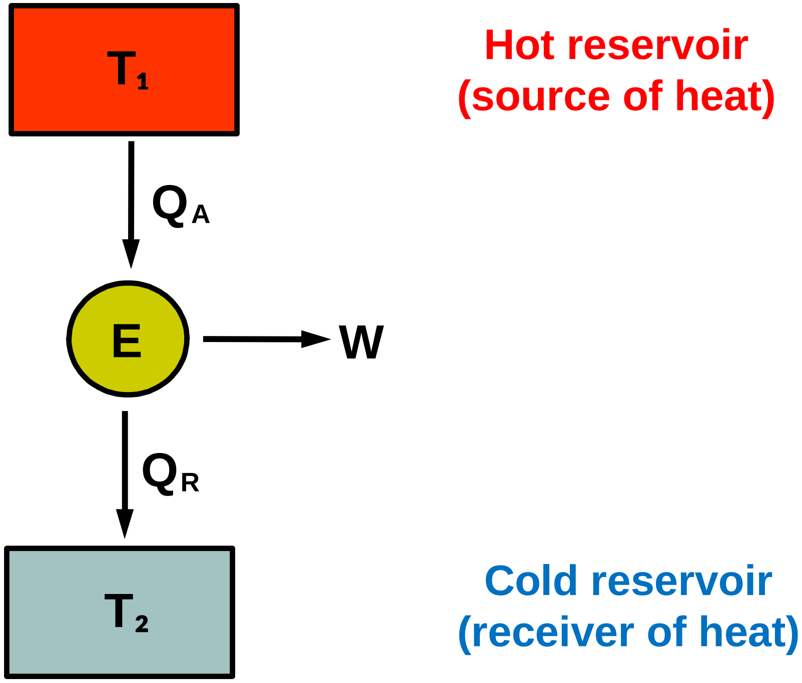


Fig. 1 Representation of a heat engine

Heat Engine and Refrigerating Machine *cont'd*

$$W = Q_A - Q_R$$

$$e = \frac{W}{Q_A} = \frac{Q_A - Q_R}{Q_A}$$

where: Q_A = the heat added

Q_R = the heat rejected

W = the net work

e = the thermal efficiency

Heat Engine and Refrigerating Machine *cont'd*

- A *refrigerating machine* will either cool or maintain a body at a temperature below that of its surroundings. A refrigerating machine may be represented by the diagram shown in Fig. 2 below.

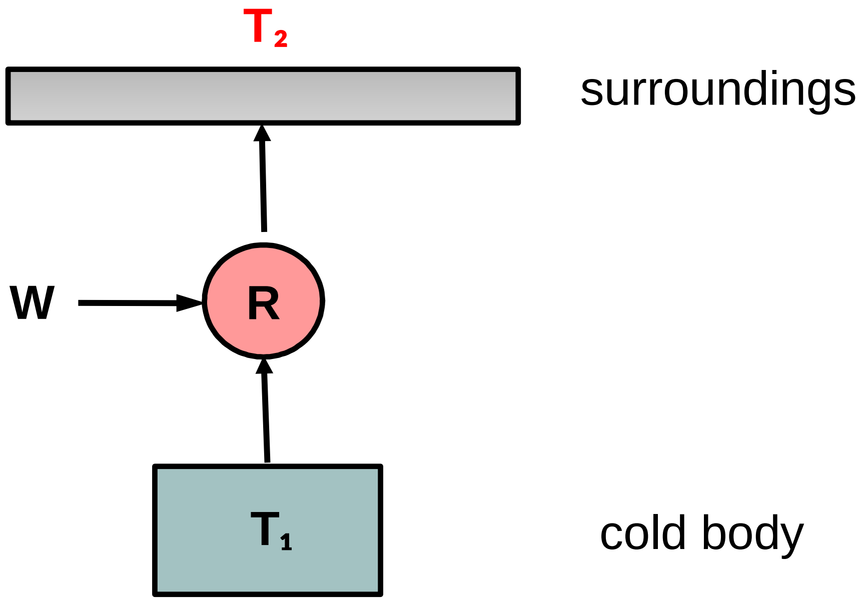


Fig. 2 Representation of a refrigerating machine

Heat Engine and Refrigerating Machine *cont'd*

- The machine R absorbs heat Q_A from the cold body at temperature T_1 and rejects heat Q_R to the surroundings at temperature T_2 and, during the process, requires work W to be done on the system.

$$W = Q_R - Q_A$$

$$COP = \frac{Q_A}{W} = \frac{Q_A}{Q_R - Q_A}$$

Heat Engine and Refrigerating Machine *cont'd*

where: Q_A = the heat absorbed from the cold body or refrigeration produced

Q_R = heat rejected to the surroundings

W = the work done or mechanical energy consumed

COP = the coefficient of performance

Heat Engine and Refrigerating Machine *cont'd*

- The performance of a heat engine is expressed by its *thermal efficiency*.
- The performance of a refrigerating machine is expressed by the ratio of useful result to work called energy ratio or *coefficient of performance*.

The Carnot Cycle

- The ***Carnot Cycle*** is the most efficient cycle conceivable.
- There are other ideal cycles as efficient as the Carnot Cycle but none more so, such a perfect cycle forms a standard of comparison for actual engines and actual cycles and also for other less efficient ideal cycles, permitting us to judge how much room there might be for improvement.
- See Fig. 3 for graphical description.

The Carnot Cycle *cont'd*

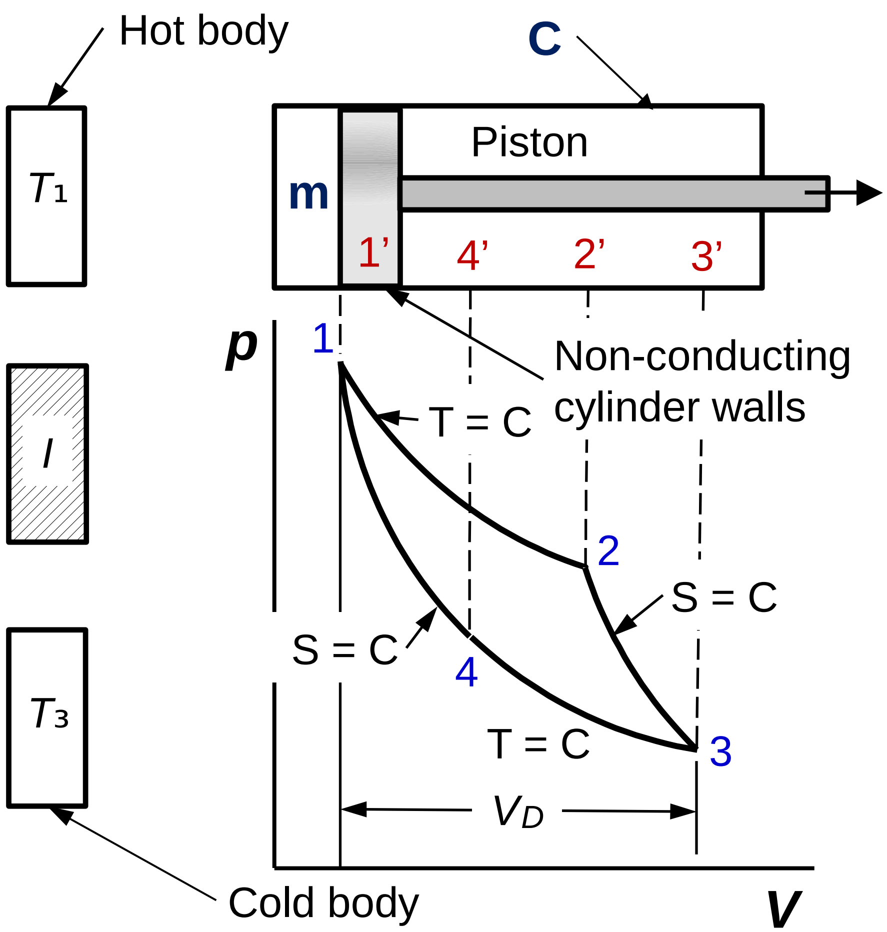


Fig. 3 – The Carnot Cycle (Graphical description)

The Carnot Cycle Operation

- A cylinder *C* contains *m* mass of a substance.
- The cylinder head, the only place where heat may enter or leave the substance (system) is placed in contact with the source of heat or hot body which has a constant temperature T_1.
- Heat flows from the hot body into the substance in the cylinder isothermally, process 1-2, and the piston moves from 1’ to 2’.
- Next, the cylinder is removed from the hot body and the insulator *I* is placed over the head of the cylinder, so that no heat may be transferred in or out.

The Carnot Cycle Operation *cont'd*

- As a result, any further process is adiabatic.
- The isentropic change 2-3 now occurs and the piston moves from 2' to 3'.
- When the piston reaches the end of the stroke 3', the insulator *I* is removed and the cylinder head is placed in contact with a receiver or sink, which remains at a constant temperature T_2.
- Heat then flows from the substance to the sink, and the isothermal compression 3-4 occurs while the piston moves from 3' to 4'.

The Carnot Cycle Operation *cont'd*

- Finally, the insulator *I* is again placed over the head and the isentropic compression 4-1 returns the substance to its initial condition, as the piston moves from 4' to 1'.
- Refer to Fig. 4 for the Carnot Cycle analysis.

The Carnot Cycle Analysis

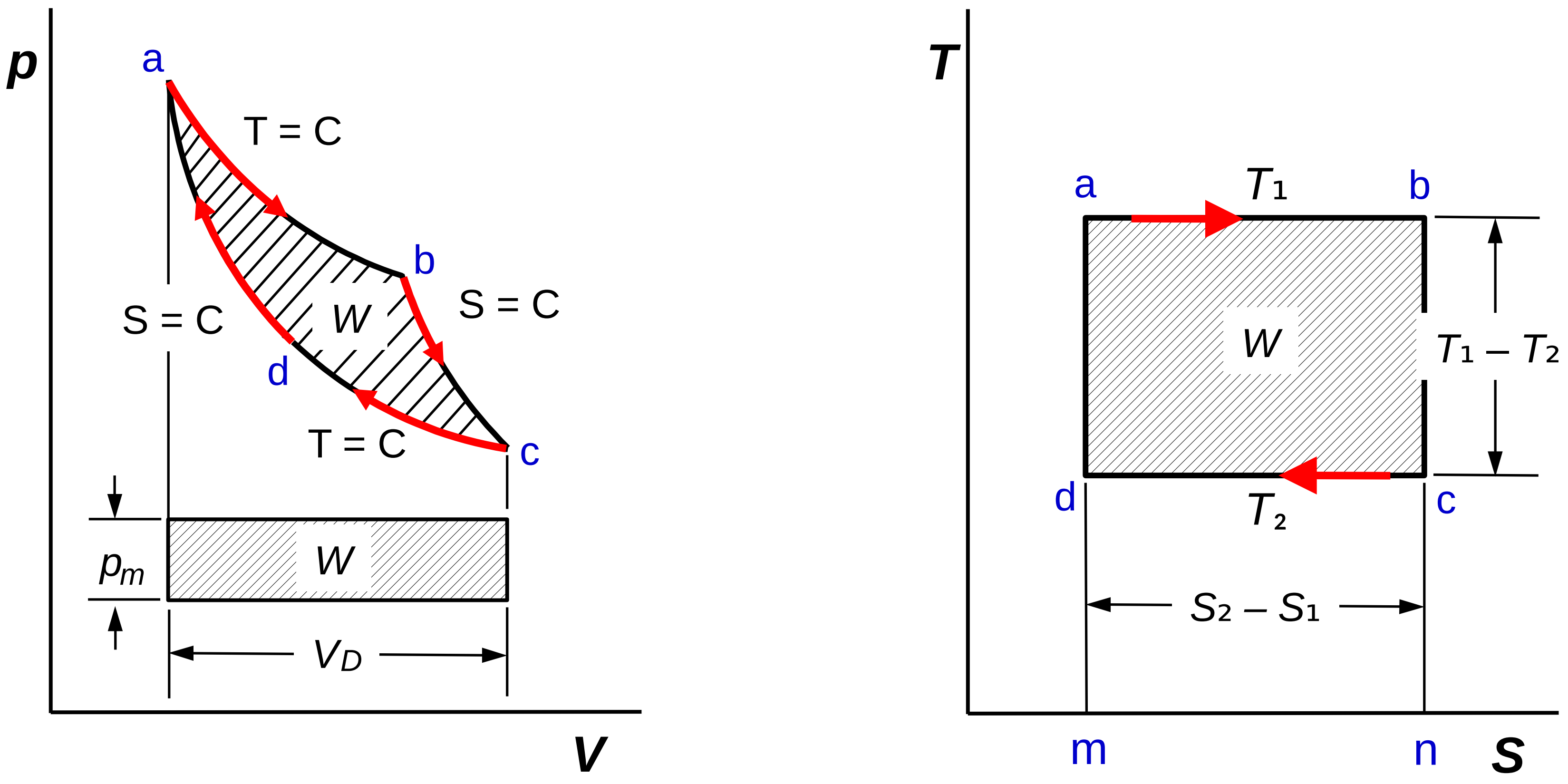


Fig. 4 – The Carnot Cycle (p-V and T-s diagrams)

The Carnot Cycle Analysis *cont'd*

- The Carnot power cycle consists of the following reversible processes:
  - Process a – b: isothermal expansion, $T_a = T_b = T_1$
  - Process b – c: isentropic expansion, $S_b = S_c$
  - Process c – d: isothermal compression, $T_c = T_d = T_2$
  - Process d – a: isentropic compression, $S_d = S_a$

$$Q_A = T_1 (S_b - S_a)$$

$$Q_R = T_2 (S_d - S_c) = - T_2 (S_c - S_d)$$

$$Q_R = T_2 (S_b - S_a)$$

The Carnot Cycle Analysis *cont'd*

$$W = Q_A - Q_R$$

$$= T_1 (S_b - S_a) - T_2 (S_b - S_a)$$

$$W = (T_1 - T_2)(S_b - S_a)$$

$$e = \frac{W}{Q} = \frac{(T_1 - T_2)(S_b - S_a)}{T_1 (S_b - S_a)}$$

$$e = \frac{T_1 - T_2}{T_1}$$

The Carnot Cycle Analysis *cont'd*

where:

Q_A = the heat added by the hot body

Q_R = the heat rejected to the cold body

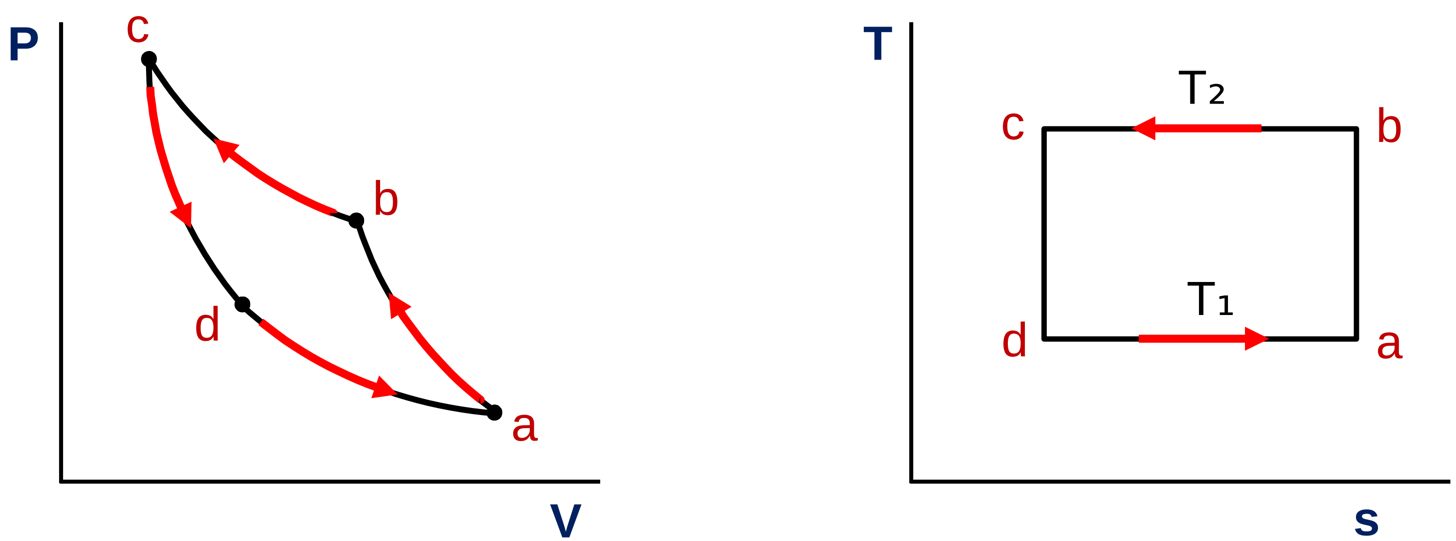
W = the work done

e = the thermal efficiency

T_1 = the temperature of the source of heat

T_2 = the temperature of the sink or receiver of the heat

Reversed Carnot Cycle



Process a-b: Isentropic compression of the working fluid with the aid of external work. The temperature of the fluid rises from T_1 to T_2 ($S_a = S_b$).
Process b-c: Isothermal compression of the working fluid during which heat is rejected at constant high temperature T_2 ($T_b = T_c = T_2$).
Process c-d: Isentropic expansion of the working fluid. The temperature of the working fluid falls from T_2 to T_1 ($S_c = S_d$).
Process d-a: Isothermal absorption of heat by the working fluid from the refrigerator at constant low temperature T_1 ($T_d = T_a = T_1$).

Reversed Carnot Cycle *cont'd*

- The reversed Carnot cycle follows the same processes as in the power producing Carnot cycle, but the cycle operates in the counter-clockwise or reverse direction.
- The formulas based on the diagram:

$$Q_A = T_1 (S_a - S_d)$$

$$Q_R = T_2 (S_d - S_c) = - T_2 (S_b - S_c)$$

$$Q_R = - T_2 (S_a - S_d)$$

Reversed Carnot Cycle *cont'd*

$$W = Q_R - Q_A$$

$$= T_2 (S_a - S_d) - T_1 (S_a - S_d)$$

$$W = (T_2 - T_1)(S_a - S_d)$$

$$COP = \frac{Q_A}{W} = \frac{T_1 (S_a - S_d)}{(T_2 - T_1)(S_a - S_d)}$$

$$COP = \frac{T_1}{T_2 - T_1}$$

Reversed Carnot Cycle *cont'd*

where: Q_A = the heat absorbed from the cold body

Q_R = the heat rejected to the hot body

W = work done on the system

COP = the coefficient of performance

T_1 = the refrigeration temperature

T_2 = the temperature of heat rejection to the surroundings

Coefficient of Performance

$$\text{COP} = \frac{\text{Heat absorbed}}{\text{Work applied}} = \frac{\text{Heat absorbed}}{\text{Heat rejected} - \text{Heat absorbed}}$$

$$\text{COP} = \frac{T_2(S_a - S_d)}{T_1(S_a - S_d) - T_2(S_a - S_d)}$$

- In simple terms, the Coefficient of Performance is the ratio of the refrigerating effect to the work of compression.

Sample problems

- PROBLEM # 1:

  A refrigerating system operates on the reversed Carnot cycle. The higher temperature of the refrigerant in the system is 120°F and the lower is 10°F. The capacity is 20 tons. Neglect losses. Determine:

  (a) Coefficient of performance

  (b) Heat rejected from the system in Btu/min.

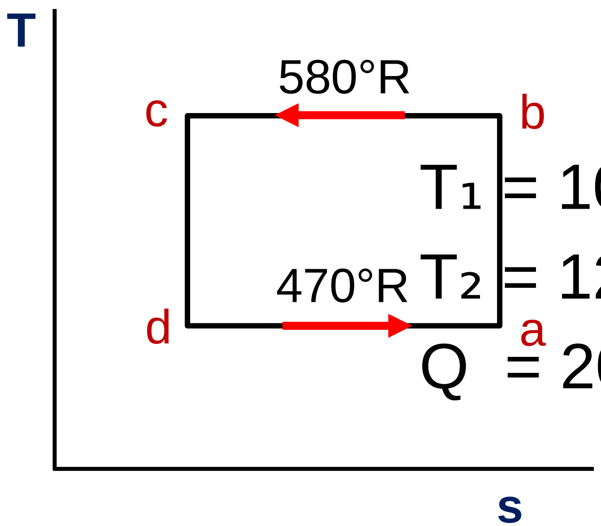
  (c) Net work in Btu/min

  NOTE: The kind of refrigerant is not given in the problem.

Sample problems *cont'd*

- PROBLEM # 1:

  Solution:



$T_1 = 10 + 460 = 470°R$

$T_2 = 120 + 460 = 580°R$

$Q = 20\ TR$

A

Sample problems *cont'd*

- PROBLEM # 1 cont'd:

Solution:

(a) $$COP = \frac{T_1}{T_2 - T_1} = \frac{470}{580 - 470} = \underline{4.273}$$

(b) $Q_A = (20)(200) = 4000$ Btu/min

$$\Delta S = \frac{Q_A}{T_1} = \frac{4000}{470} = 8.511 \text{ Btu/(min)(°R)}$$

Sample problems *cont'd*

- PROBLEM # 1 cont'd:

Solution cont'd:

$Q = T_{R2}(\Delta S) = (580)(8.511) =$ <u>4936 Btu/min</u>

(c) $W = (T_2 - T_1)(\Delta S) = (580 - 470)(8.511)$

$W =$ <u>936 Btu/min</u>

(d) $W = \dfrac{936}{42.4} =$ <u>22.08 hp</u>

Sample problems *cont'd*

- PROBLEM # 2:

A refrigeration system operates on the reversed Carnot cycle. The minimum and maximum temperatures are minus 25°C and plus 72°C, respectively. If the heta rejected at the condenser is 6000 kJ/min, draw the T-s diagram and find

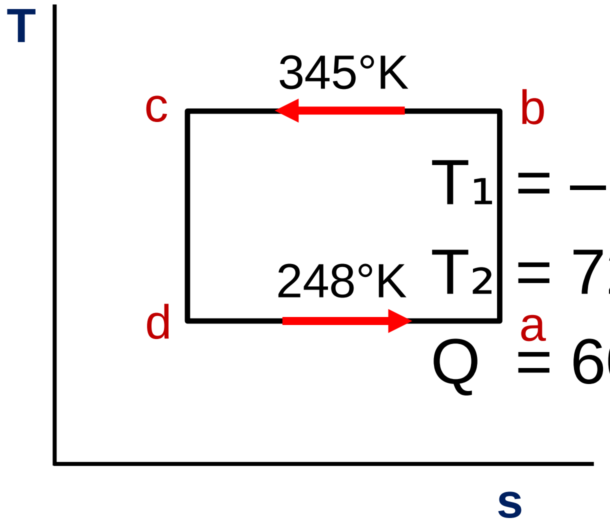
(a) power input required, and

(b) tons of refrigeration developed.

Sample problems *cont'd*

- PROBLEM # 2 cont'd:

  Solution:



$T_1 = -25 + 273 = 248°K$

$T_2 = 72 + 273 = 345°K$

$Q_R = 6000$ kJ/min

Sample problems *cont'd*

- PROBLEM # 2 cont'd:

Solution cont'd:

(a) $$\Delta S = \frac{Q_R}{T_2} = \frac{6000}{345} = 17.39 \text{ kJ/(min)(K)}$$

$W = (T_2 - T_1)(\Delta S) = (345 - 248)(17.39)$

$W = $ 1686.8 kJ/min

(b) $Q_A = (T_1)(\Delta S) = (248)(17.39) = 4313$ kJ/min

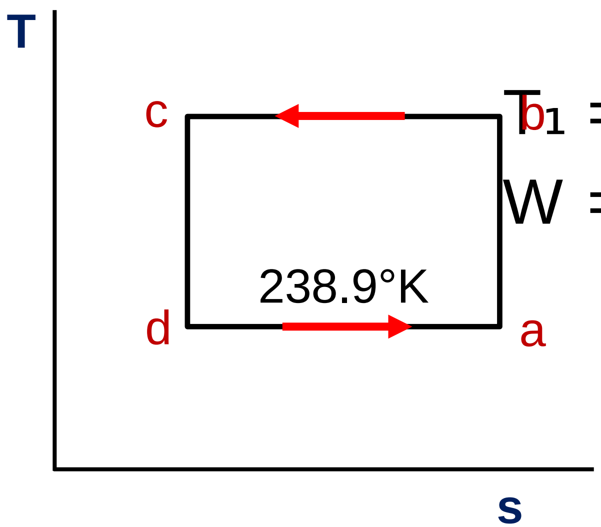
$$Q_A = \frac{4313}{211} = 20.44 \text{ TR}$$

Sample problems *cont'd*

- PROBLEM # 3:

  The power requirement of a Carnot refrigerator in maintaining a low temperature region at 238.9°K is 1.1 kW per ton. Find (a) COP, (b) T_2, and (c) the heat rejected.

  Solution:



T_1 = 238.9°K

W = 1.1 kW/TR

Sample problems *cont'd*

- PROBLEM # 3 cont'd:

Solution:

(a) $Q_A = 1$ TR or 3.52 kW

$W = 1.1$ kW

$$COP = \frac{Q_A}{W} = \frac{3.52\ kW}{1.1\ kW} = \underline{3.2}$$

(b) $$COP = \frac{T_1}{T_2 - T_1}$$

$$3.2 = \frac{238.9}{T_2 - 238.9}$$

Sample problems *cont'd*

- PROBLEM # 3 cont'd:

Solution:

$T_2 = \underline{313.6°K}$

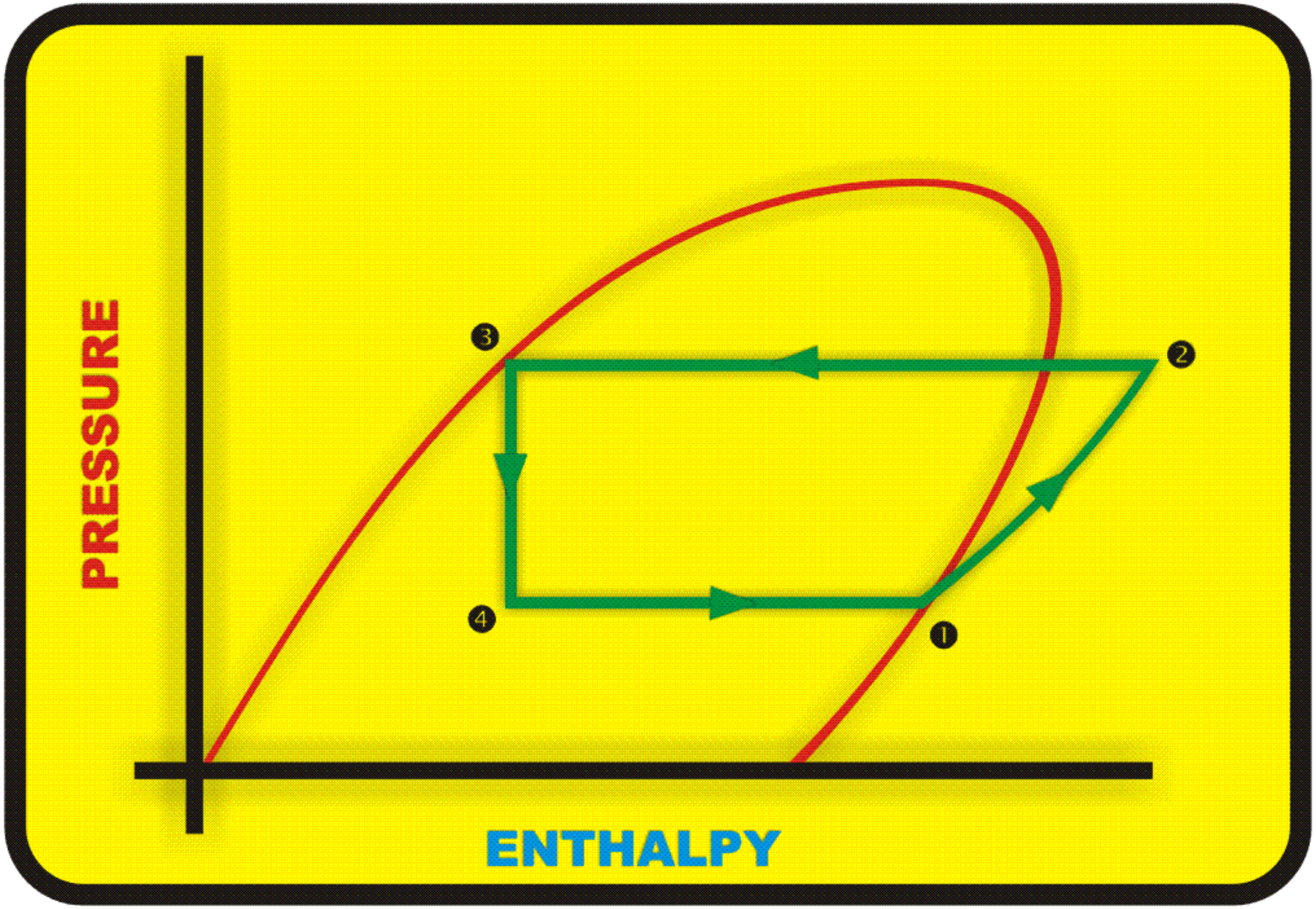
(c) $$\Delta S = \frac{W}{T_2 - T_1} = \frac{1.1 \text{ kJ/s}}{(313.6 - 238.9)\ °K}$$

$\Delta S = 0.01473$ kJ/(s)(°K)

$Q_R = (T_2)(\Delta S) = (313.6°K)(0.01473 \text{ kJ/s-°K})$

$= \underline{4.62 \text{ kJ/s or } 4.62 \text{ kW}}$

Vapor Compression Cycle



Vapor Compression Cycle

- The processes which comprises the standard vapor-compression cycle are:
  - 1-2: <u>Reversible and adiabatic compression</u> from saturated vapor to the condenser pressure
  - 2-3: <u>Reversible rejection of heat at constant pressure</u> de-superheating and condensation
  - 3-4: <u>Irreversible expansion at constant enthalpy</u> from saturated liquid to the evaporator pressure
  - 4-1: <u>Reversible addition of heat at constant pressure</u> in evaporation to saturated vapor

The Refrigeration Cycle

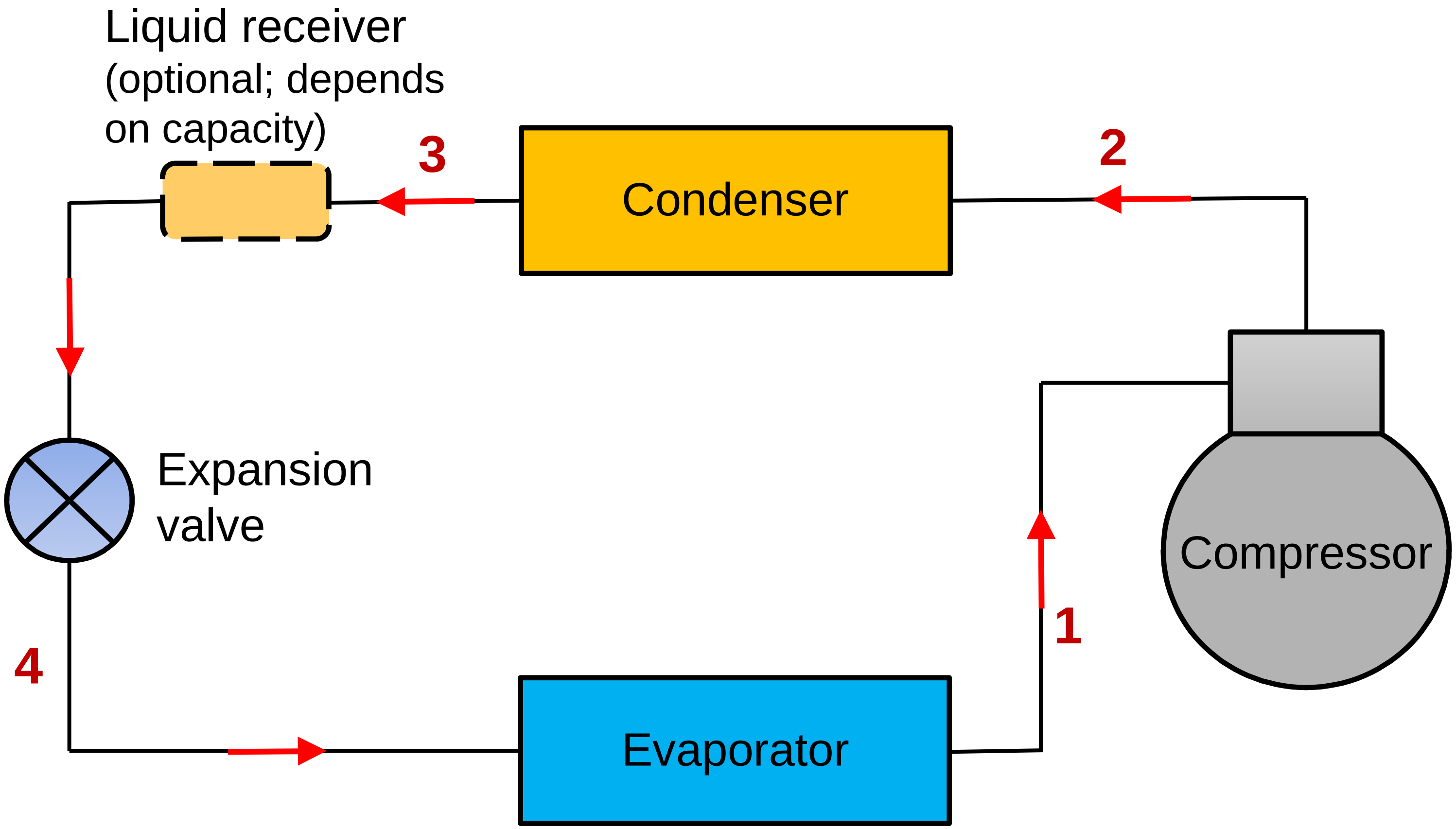


Fig. 5 – VAPOR COMPRESSION REFRIGERATION SYSTEM

The Refrigeration Cycle Operation

- The cycle of operation, that is the cooling process, consists of four separate steps as follows:
  1. ***The vaporizing process***. As the low temperature, low pressure refrigerant in the *evaporator* absorbs the heat from the material and space that is being refrigerated, <u>it is transformed from a liquid to a vapor in the process</u>.
  2. ***The compressing process***. The *compressor* draws the vapor from the evaporator, <u>it then compresses this vapor until its temperature is above that of the condensing medium</u>.

The Refrigeration Cycle Operation *cont'd*

3. ***The condensing process***. When the compressor has raised the temperature of the vapor to a temperature above that of the condensing medium, <u>the heat of the vapor will flow to the condensing medium and so condense the refrigerant to a high pressure liquid</u>. This high pressure liquid then <u>flows to the receiver where it is stored until it is supplied to the cooling unit through the expansion valve</u>.
4. ***The pressure reducing process***. As the compressor withdraws the refrigerant vapor from the evaporator, <u>the cooling unit must be supplied with more low temperature, low pressure refrigerant capable of</u>

The Refrigeration Cycle Operation *cont'd*

absorbing heat. This is accomplished by a liquid control valve known as an *expansion valve*. This valve reduces the pressure of high pressure liquid from the receiver to a low pressure liquid capable of absorbing heat, it maintains a constant supply of liquid in the evaporator and acts as a dividing point between the high pressure and the low pressure side of the system.

Division of the Refrigeration System

- A refrigeration system is divided into two parts according to pressure exerted by the refrigerant in the parts:
  - ***Low pressure part***. This consists of the refrigerant flow control (expansion valve), the evaporator, and the suction line. The pressure exerted in these parts is low under which the refrigerant is vaporizing in the evaporator.

  This pressure is known variously as the "low side pressure," the "evaporator pressure," the "suction pressure," or the "back pressure."

Division of the Refrigeration System *cont'd*

- ***High pressure part*** or "high side" consists of the compressor, the discharge or "hot gas" line, the condenser, the receiver tank, and the liquid line. The pressure exerted in these parts is high under which the refrigerant is condensing in the condenser.

  This pressure is called the "condensing pressure," the "discharge pressure," or, more often, the "head pressure."

- The dividing points (Fig. 6) between the high and low pressure sides of the system are:
  - *Refrigerant flow control (expansion valve)* where the

Division of the Refrigeration System *cont'd*

the refrigerant is reduced from the condensing pressure to the vaporizing pressure.

- *Discharge valves* in the compressor through which the high pressure vapor is exhausted after compression.

- High side and low side pressures can be read directly using a refrigerant gage manifold, Figs. 7 and 8.

Division of the Refrigeration System *cont'd*

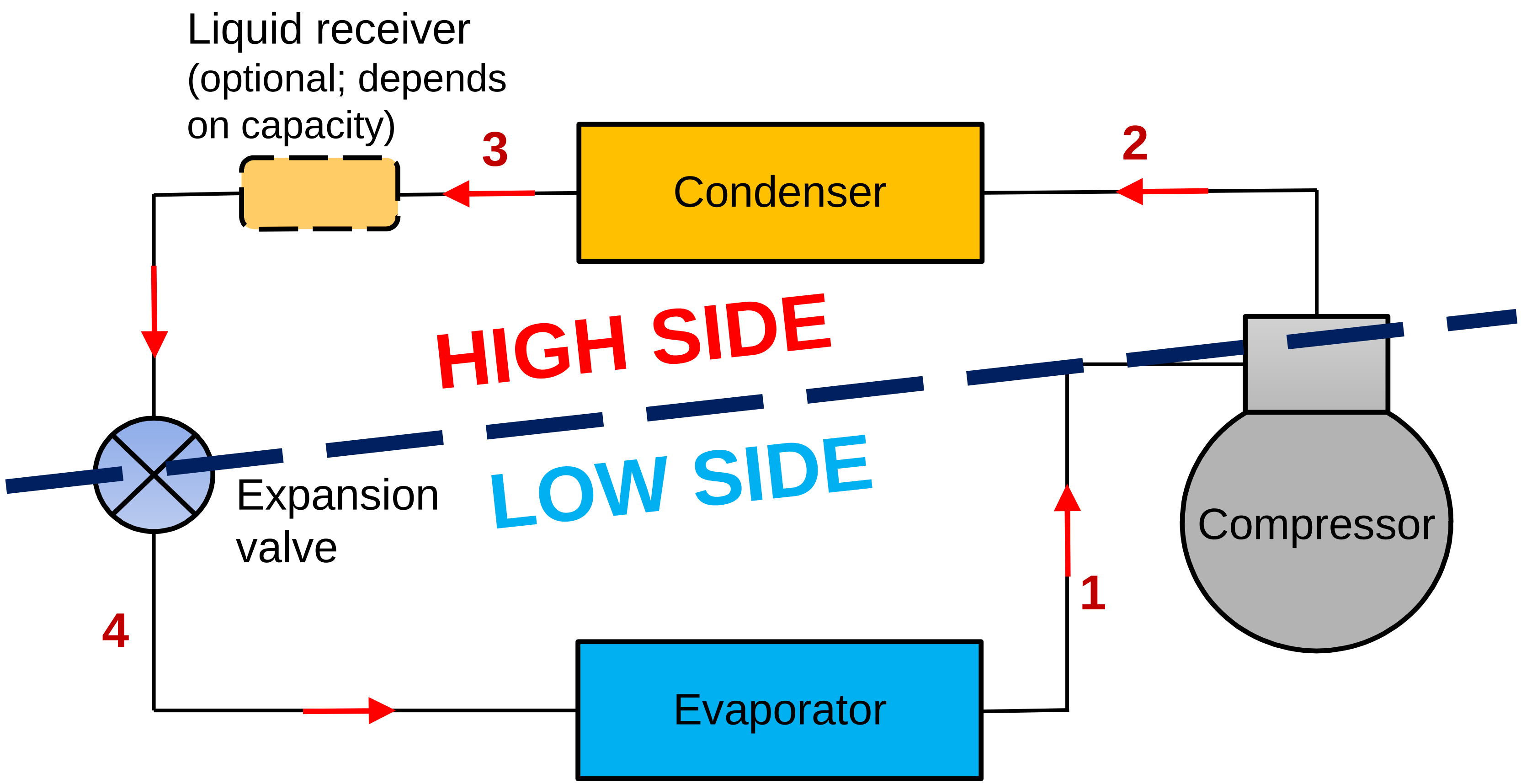


Fig. 6 – HIGH SIDE AND LOW SIDE OF A REFRIGERATION SYSTEM

Division of the Refrigeration System *cont'd*

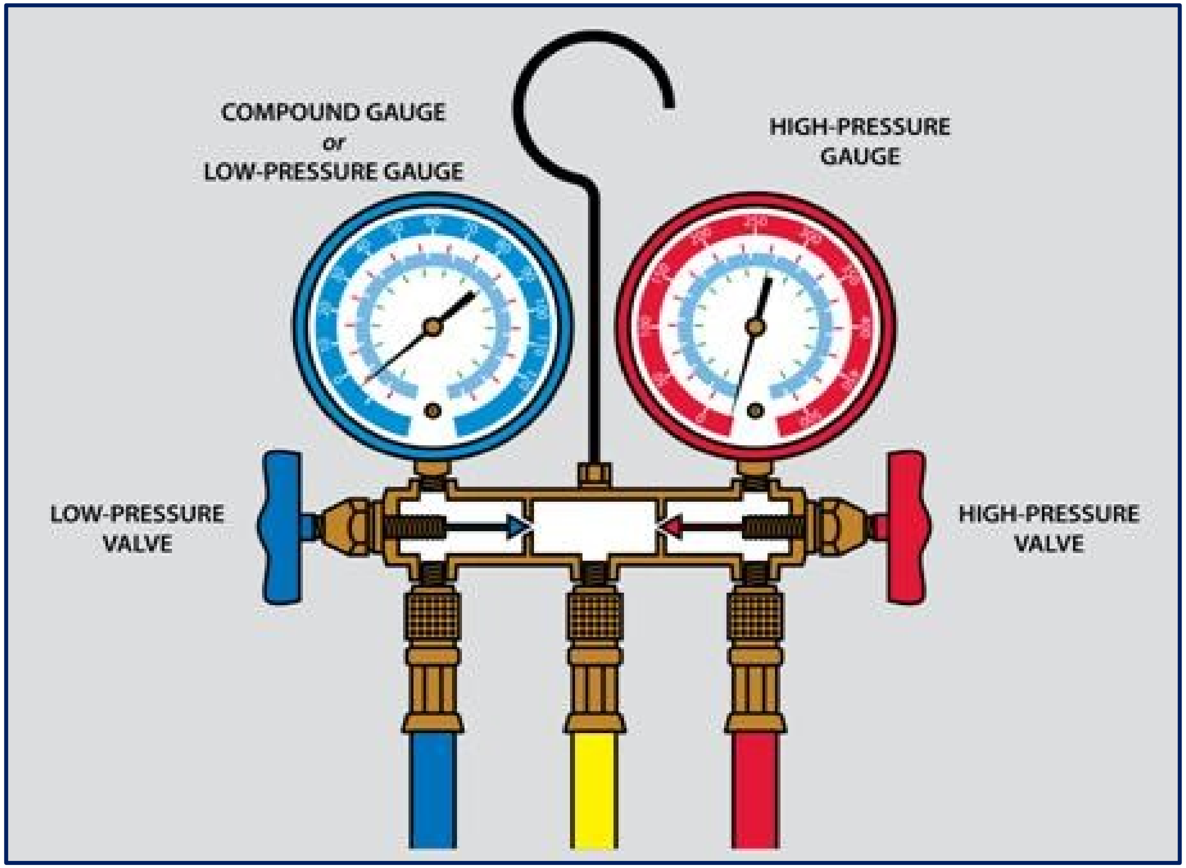


Fig. 7 – Refrigeration gage manifold (portable)

Division of the Refrigeration System *cont'd*

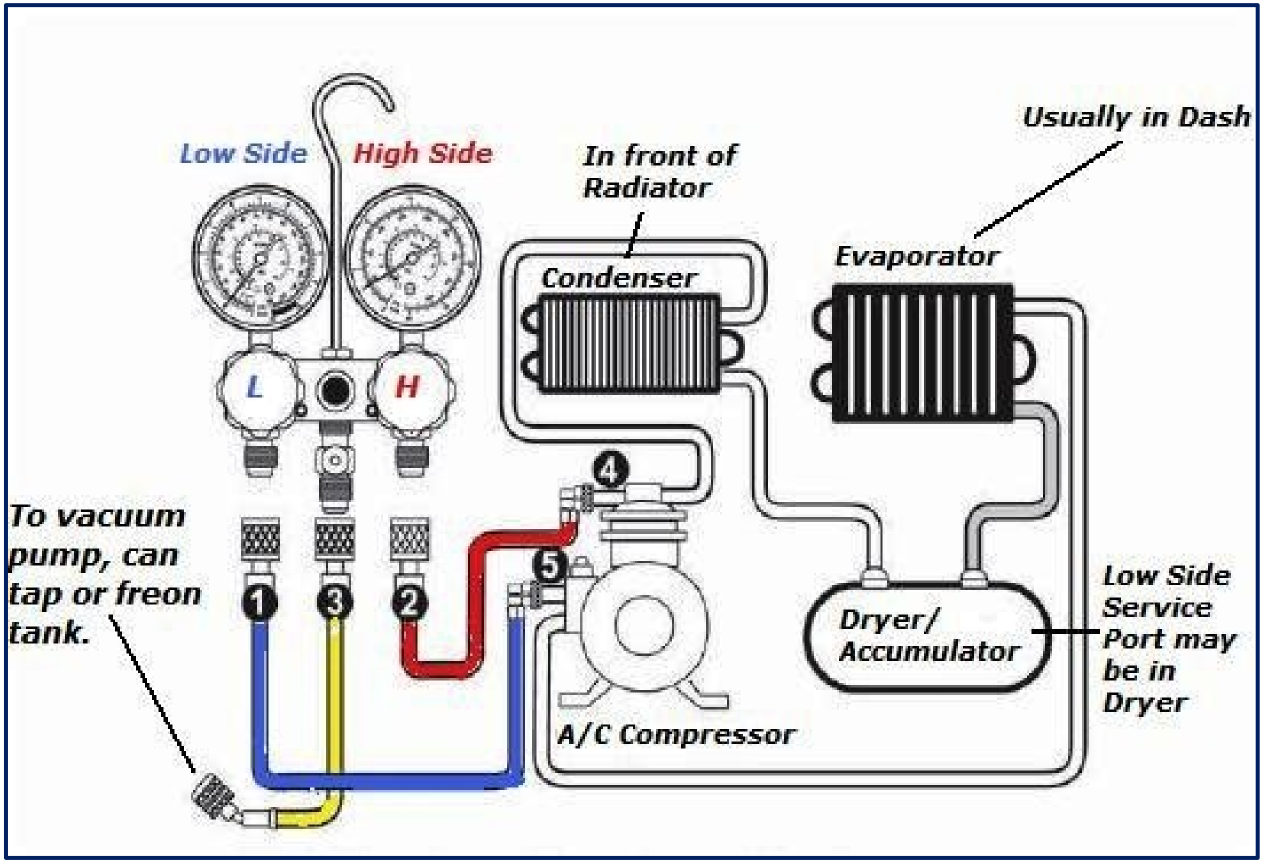


Fig. 8 – Refrigeration gage reading the high side and low side pressures

Distribution of Refrigeration

- There are two known methods of distributing refrigeration:
  - *Direct expansion (DX) system*.

    The volatile refrigerant <u>is allowed to expand and evaporate in a pipe or coil placed in the space to be cooled</u>, where the refrigerant absorbs heat from the material or space to be cooled (Fig. 9).

    This method of utilizing refrigeration is <u>used in small cold storage rooms, in freezer rooms and other locations where possible losses due to leakage of refrigerant would be low</u>.

Distribution of Refrigeration *cont'd*

- *Indirect expansion (Chilled Water/Brine) system*.

  Some refrigeration medium, such as brine (sodium chloride or calcium chloride) is cooled down by direct expansion of the refrigerant, and is then pumped through the material or space to be cooled, where it absorbs its sensible heat (Fig. 10).

  Brine systems (or more popularly known as chilled water systems) are used to advantage in large installations, where the danger due to leakage of the large amount of refrigerant is important, and in rooms or series of rooms of fluctuating temperatures.

Direct Expansion (DX) System

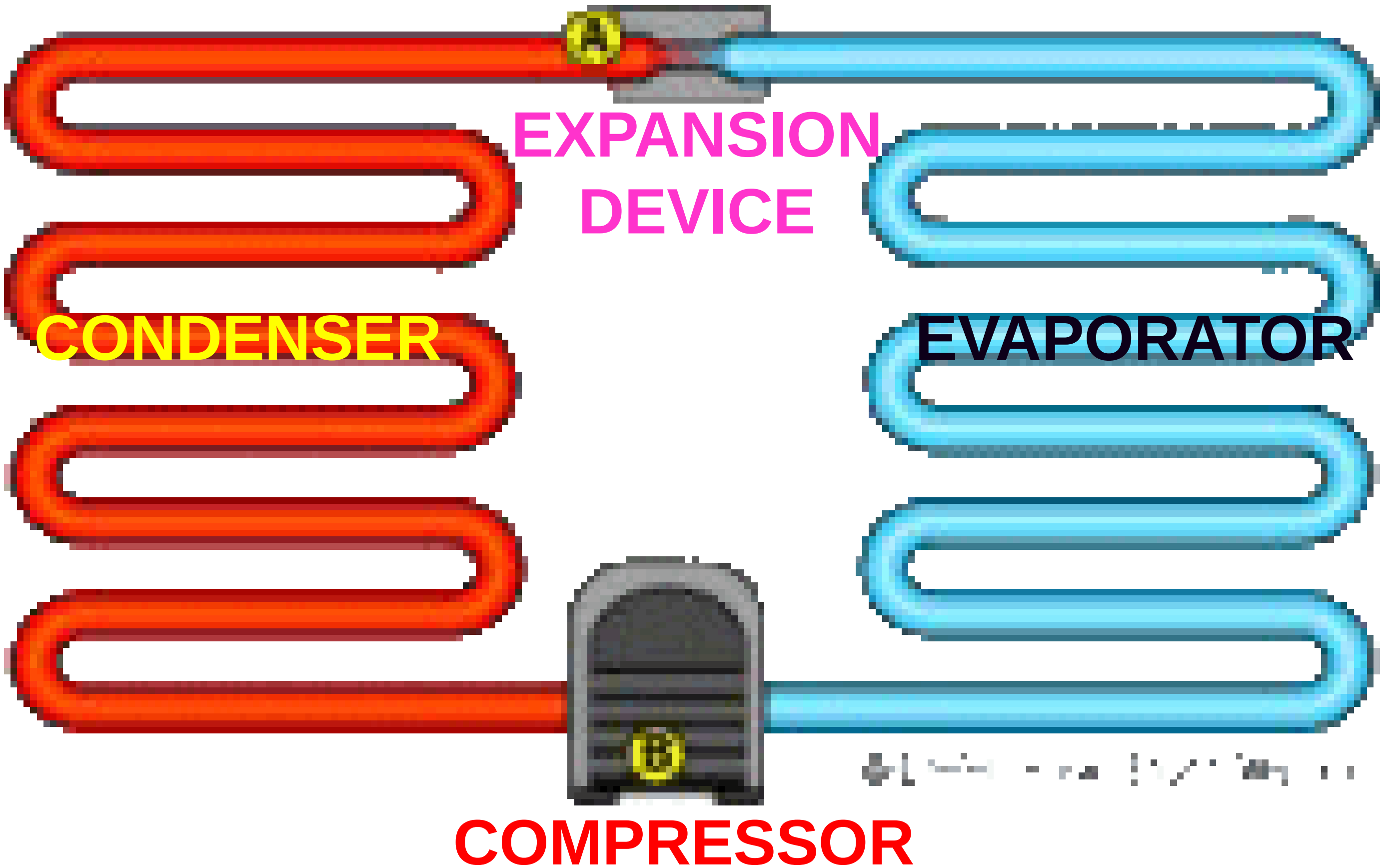
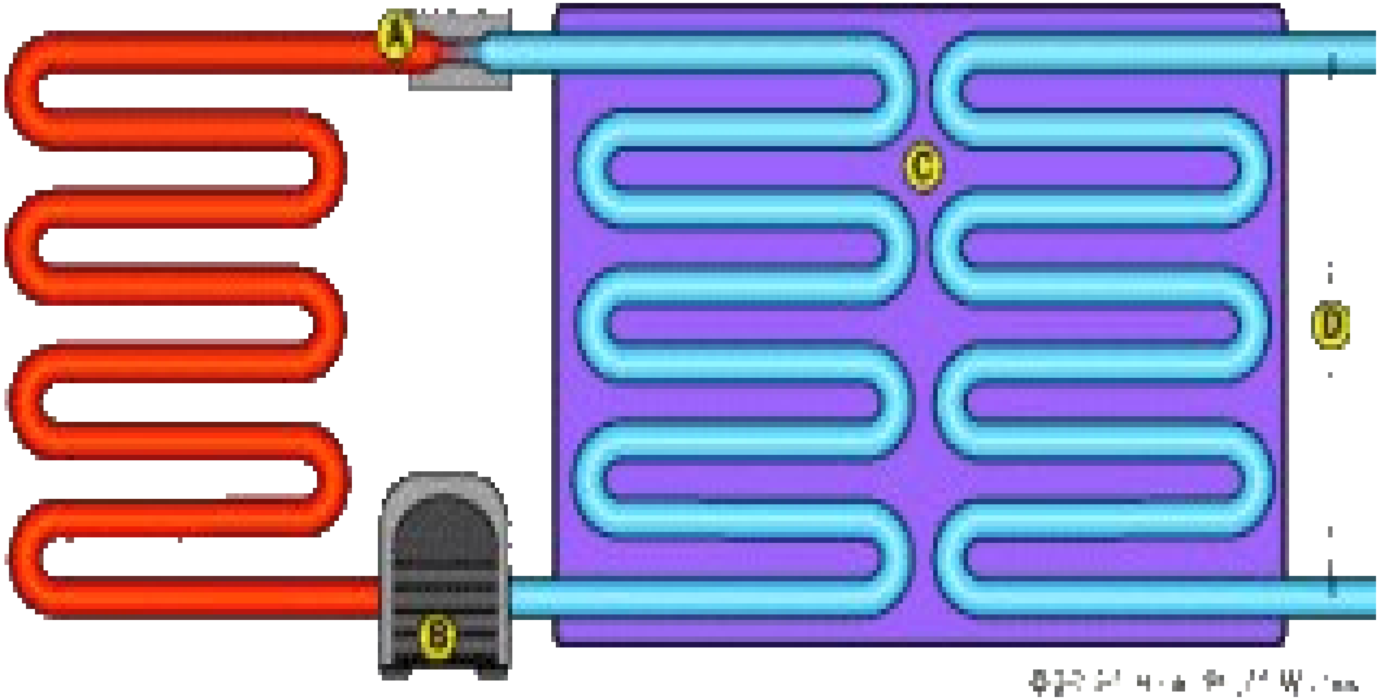


Fig. 9 – Typical Direct Expansion (DX) system

Chilled Water System



A. HOT GAS CIRCUIT

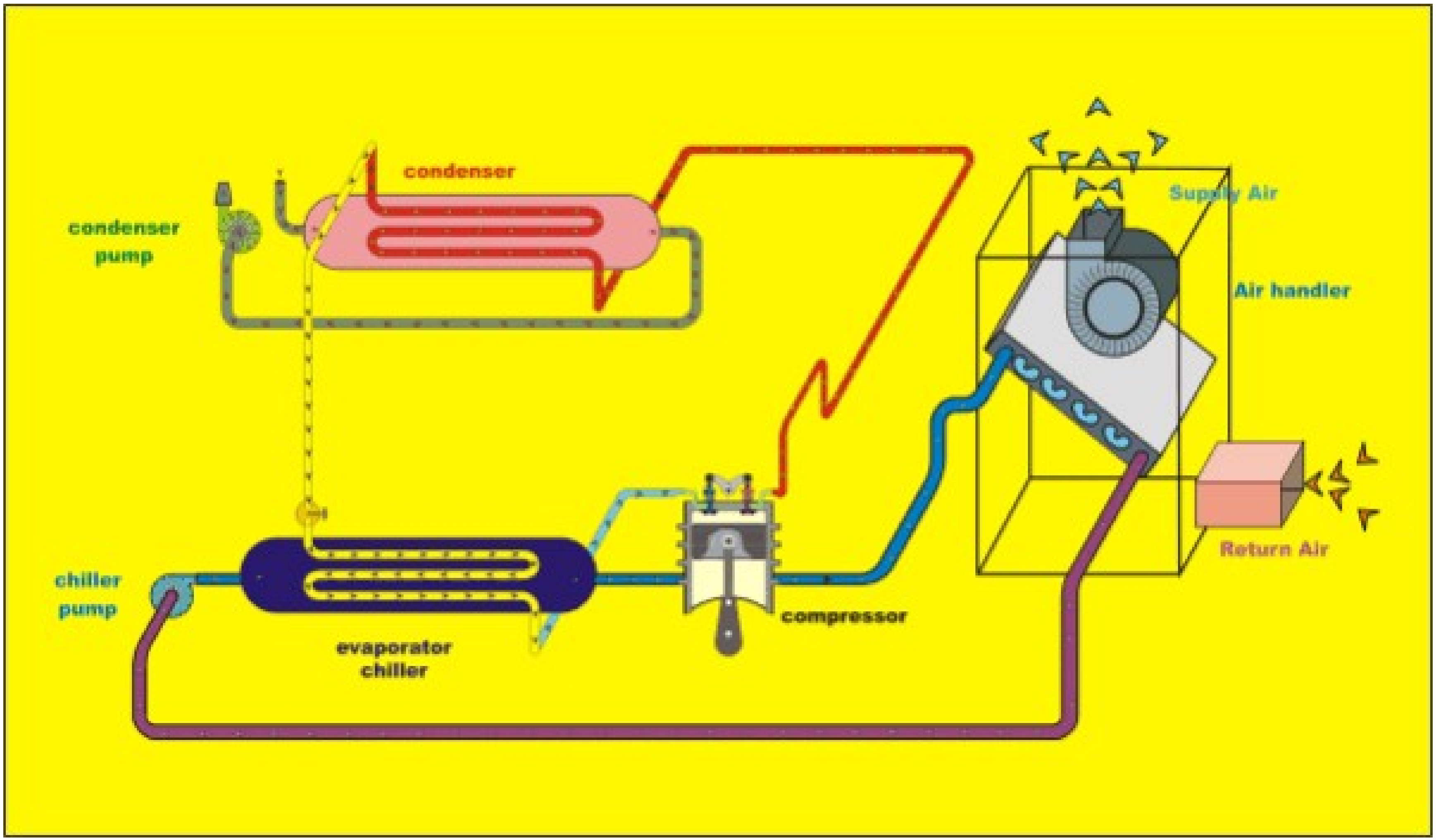
B. COLD GAS TO COMPRESSOR CIRCUIT

C. CHILLER

D. CHILLED WATER CIRCUIT

Fig. 10 – Typical Chilled Water (CHW) system

Chilled Water System Operation



EER – Energy Efficiency Ratio

- Energy Efficiency Ratio is a measure of the performance of the equipment.

$$EER = \frac{R.\ E.}{P_{ELECTRIC}}$$

$$EER = \frac{Btu/hr}{watts}$$

Where:

EER = Energy Efficiency Ratio

R. E. = Refrigerating Capacity of cooling coil in BTU/hr

$P_{ELECTRIC}$ = Motor power input in watts

Any Questions?

Assignment # 1 – June 11, 2015

- For next meeting, submit in one sheet of bond paper. Write your name, subject/section, date and write the problem statement. Please write legibly. Non-compliance will mean non-acceptance of your assignment.

1. A reverse Carnot cycle is used for refrigeration and rejects 1,000 kW of heat at 340K while receiving heat at 250K. Determine (a) the COP, (b) the power required, and (c) the refrigerating effect.
2. A reversed Carnot cycle has a refrigerating COP of 4.

   (a) What is the ratio Tmax/Tmin?

   (b) If the work input is 6 kW, what will be the maximum refrigerating effect; kJ/min and TR.