Lesson

4

Review of fundamental principles – Thermodynamics : Part I

The main objective of this lesson and the subsequent lesson is to review fundamental principles of thermodynamics pertinent to refrigeration and air conditioning. The specific objectives of this part are to:

1. Introduce and define important thermodynamic concepts such as thermodynamic system, path and point functions, thermodynamic process, cycle, heat, work etc. *(Sections 4.2 and 4.3)*
2. State the four fundamental laws of thermodynamics *(Section 4.4)*
3. Apply first law of thermodynamics to closed and open systems and develop relevant equations *(Section 4.4)*
4. Introduce and define thermodynamic properties such as internal energy and enthalpy *(Section 4.4)*
5. Discuss the importance of second law of thermodynamics and state Carnot theorems *(Section 4.4)*
6. Define and distinguish the differences between heat engine, refrigerator and heat pump *(Section 4.4)*
7. Obtain expressions for Carnot efficiency of heat engine, refrigerator and heat pump *(Section 4.4)*
8. State Clausius inequality and introduce the property ‘entropy’ *(Section 4.4)*

At the end of the lesson the student should be able to:

1. Identify path function and point functions
2. Define heat and work
3. Apply first law of thermodynamics to open and closed systems
4. State second law of thermodynamics
5. Define heat engine, refrigerator and heat pump
6. Apply second law of thermodynamics to evaluate efficiencies of reversible cycles
7. State Clausius inequality and define entropy
8. Define reversible and irreversible processes
9. State the principle of increase of entropy

4.1. Introduction

Refrigeration and air conditioning involves various processes such as compression, expansion, cooling, heating, humidification, de-humidification, air purification, air distribution etc. In all these processes, there is an exchange of mass, momentum and energy. All these exchanges are subject to certain fundamental laws. Hence to understand and analyse refrigeration and air conditioning systems, a basic knowledge of the laws of thermodynamics, fluid mechanics and heat transfer that govern these processes is essential. It is assumed that the reader has studied courses in engineering thermodynamics, fluid mechanics and heat transfer. This chapter reviews some of the fundamental concepts of thermodynamics pertinent to refrigeration and air-conditioning.

4.2. Definitions

Thermodynamics is the study of energy interactions between *systems* and the effect of these interactions on the system *properties*. Energy transfer between systems takes place in the form of *heat and/or work*. Thermodynamics deals with *systems in equilibrium*.

A thermodynamic system is defined as a quantity of matter of fixed mass and identity upon which attention is focused for study. In simple terms, a system is whatever we want to study. A system could be as simple as a gas in a cylinder or as complex as a nuclear power plant. Everything external to the system is the *surroundings*. The system is separated from the surroundings by the *system boundaries*. Thermodynamic systems can be further classified into *closed systems, open systems and isolated systems*.

A control volume, which may be considered as an open system, is defined as a specified region in space upon which attention is focused. The control volume is separated from the surroundings by a *control surface*. Both mass and energy can enter or leave the control volume.

The first and an extremely important step in the study of thermodynamics is to choose and identify the system properly and show the system boundaries clearly.

A process is defined as the path of thermodynamic states which the system passes through as it goes from an initial state to a final state. In refrigeration and air conditioning one encounters a wide variety of processes. Understanding the nature of the process path is very important as heat and work depend on the path.

A system is said to have undergone a *cycle* if beginning with an initial state it goes through different processes and finally arrives at the initial state.

4.2.1. Heat and work:

Heat is energy transferred between a system and its surroundings by virtue of a temperature difference only. The different modes of heat transfer are: conduction, convection and radiation.

Heat is a way of changing the energy of a system by virtue of a temperature difference only. Any other means for changing the energy of a system is called *work*. We can have push-pull work (*e.g.* in a piston-cylinder, lifting a weight), electric and magnetic work (*e.g.* an electric motor), chemical work, surface tension work, elastic work, *etc.*

Mechanical modes of work: In mechanics work is said to be done when a force ‘F’ moves through a distance ‘dx’. When this force is a mechanical force, we call the work done as a mechanical mode of work. The classical examples of mechanical mode of work are:

1. Moving system boundary work
2. Rotating shaft work
3. Elastic work, and
4. Surface tension work

For a moving system boundary work, the work done during a process 1-2 is given by:

$$ {}_1W_2 = \int_1^2 p.dV \tag{4.1} $$

where ‘p’ is the pressure acting on the system boundary and ‘dV’ is the differential volume. It is assumed that the process is carried out very slowly so that at each instant of time the system is in equilibrium. Typically such a process is called a quasi-equilibrium process.

For rigid containers, volume is constant, hence moving boundary work is zero in this case. For other systems, in order to find the work done one needs to know the relation between pressure p and volume V during the process.
Sign convention for work and heat transfer: Most thermodynamics books consider the work done by the system to be positive and the work done on the system to be negative. The heat transfer to the system is considered to be positive and heat rejected by the system is considered to be negative. The same convention is followed throughout this course.

4.2.2. Thermodynamic Functions:

There are two types of functions defined in thermodynamics, path function and point function.

Path function depends on history of the system (or path by which system arrived at a given state). Examples for path functions are work and heat. *Point function* does not depend on the history (or path) of the system. It only depends on the state of the system. Examples of point functions are: temperature, pressure, density, mass, volume, enthalpy, entropy, internal energy etc. Path functions are not properties of the system, while point functions are properties of the system. Change in point function can be obtained by from the initial and final values of the function, whereas path has to defined in order to evaluate path functions. Figure 4.1 shows the difference between point and path functions. Processes A and B have same initial and final states, hence, the change in volume (DV_A and DV_B) for both these processes is same (3 m^3), as volume is a point function, whereas the work transferred (W_A and W_B) for the processes is different since work is a path function. It should also be noted that the cyclic integrals of all point functions is zero, while the cyclic integrals of path functions may be or may not be zero.

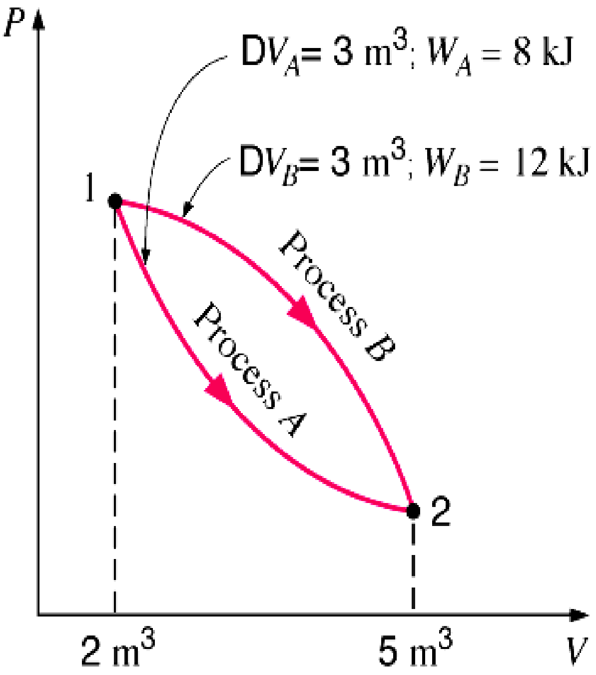


Fig. 4.1. *Difference between point and path functions*

4.3. Thermodynamic properties

A system is specified and analyzed in terms of its *properties*. A property is any characteristic or attribute of matter, which can be evaluated quantitatively. The amount of energy transferred in a given process, work done, energy stored etc. are all evaluated in terms of the changes of the system properties.
A thermodynamic property depends only on the state of the system and is independent of the path by which the system arrived at the given state. Hence all thermodynamic properties are point functions. Thermodynamic properties can be either intensive (independent of size/mass, e.g. temperature, pressure, density) or extensive (dependent on size/mass, e.g. mass, volume)

Thermodynamic properties relevant to refrigeration and air conditioning systems are temperature, pressure, volume, density, specific heat, enthalpy, entropy etc.

It is to be noted that heat and work are not properties of a system.

Some of the properties, with which we are already familiar, are: temperature, pressure, density, specific volume, specific heat etc. Thermodynamics introduces certain new properties such as internal energy, enthalpy, entropy etc. These properties will be described in due course.

4.3.1. State postulate:

This postulate states that the number of independent intensive thermodynamic properties required to specify the state of a closed system that is:

a) Subject to conditions of local equilibrium
b) Exposed to ‘n’ different (non-chemical) work modes of energy transport, and
c) Composed of ‘m’ different pure substances

is (n+m). For a pure substance (m = 1) subjected to only one work mode (n = 1) two independent intensive properties are required to fix the state of the system completely (n + m = 2). Such a system is called a *simple system*. A pure gas or vapour under compression or expansion is an example of a simple system. Here the work mode is moving system boundary work.

4.4. Fundamental laws of Thermodynamics

Classical thermodynamics is based upon four empirical principles called zeroth, first, second and third laws of thermodynamics. These laws define thermodynamic properties, which are of great importance in understanding of thermodynamic principles. Zeroth law defines temperature; first law defines internal energy; second law defines entropy and the third law can be used to obtain absolute entropy values. The above four thermodynamic laws are based on human observation of natural phenomena; they are not mathematically derived equations. Since no exceptions to these have been observed; these are accepted as laws.

Conservation of mass is a fundamental concept, which states that mass is neither created nor destroyed.

The *Zeroth law of thermodynamics* states that when two systems are in thermal equilibrium with a third system, then they in turn are in thermal equilibrium with each other. This implies that some property must be same for the three systems. This property is temperature. Thus this law is the basis for temperature measurement. Equality of temperature is a necessary and sufficient condition for thermal equilibrium, *i.e.* no transfer of heat.

The *First law of thermodynamics* is a statement of law of conservation of energy. Also, according to this law, heat and work are interchangeable. Any system that violates the first law (i.e., creates or destroys energy) is known as a Perpetual Motion Machine (PMM) of first kind. For a system undergoing a cyclic process, the first law of thermodynamics is given by:

$$\oint \delta Q = \oint \delta W \tag{4.2}$$

where $\oint \delta Q = \text{net heat transfer during the cycle}$
$\oint \delta W = \text{net work transfer during the cycle}$

Equation (4.2) can be written as:

$$\oint (\delta Q - \delta W) = 0 \tag{4.3}$$

This implies that $(\delta Q - \delta W)$ must be a point function or property of the system. This property is termed as *internal energy,* **U**. Mathematically, internal energy can be written as:

$$dU = \delta Q - \delta W \tag{4.4}$$

The internal energy of a system represents a sum total of all forms of energy viz. thermal, molecular, lattice, nuclear, rotational, vibrational etc.

4.4.1. First law of thermodynamics for a closed system:

Let the internal energy of a closed system at an equilibrium state 1 be U_1. If ${}_1Q_2$ amount of heat is transferred across its boundary and ${}_1W_2$ is the amount of work done by the system and the system is allowed to come to an equilibrium state 2. Then integration of Eqn. (4.4) yields,

$$U_2 - U_1 = {}_1Q_2 - {}_1W_2 \tag{4.5}$$

If m is the mass of the system and u denotes the specific internal energy of the system then,

$$m(u_2 - u_1) = m({}_1q_2 - {}_1w_2) \tag{4.6}$$

$$\text{or, } u_2 - u_1 = {}_1q_2 - {}_1w_2 \tag{4.7}$$

where, ${}_1q_2$ and ${}_1w_2$ are heat transfer and work done per unit mass of the system.

Flow Work:

In an open system some matter, usually fluid enters and leaves the system. It requires flow work for the fluid to enter the system against the system pressure and at the same time flow work is required to expel the fluid from the system. It can be shown that the specific flow work is given by the product of pressure, p and specific volume, v, i.e., flow work = pv.

Enthalpy:

In the analysis of open systems, it is convenient to combine the specific flow work '*pv*' with internal energy '*u*' as both of them increase the energy of the system. The sum of specific internal energy and specific flow work is an intensive property of the system and is called specific enthalpy, h. Thus specific enthalpy, h is given by:

$$h = u + pv \tag{4.8}$$

4.4.2. First law of thermodynamics for open system:

For an open system shown in Figure 4.2, m_1 and m_2 are the mass flow rates at inlet and outlet, h_1 and h_2 are the specific enthalpies at inlet and outlet, V_1 and V_2 are the inlet and outlet velocities and z_1 and z_2 are the heights at inlet and outlet with reference to a datum; q and w are the rate of heat and work transfer to the system and E is the total energy of the system.

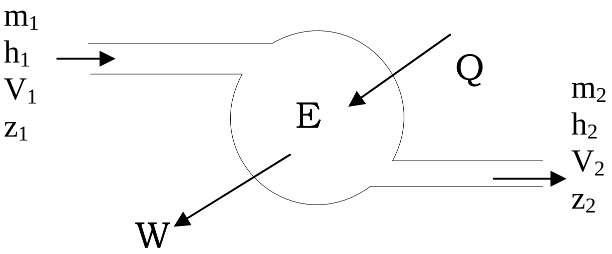


Fig. 4.2. First law of thermodynamics for an open system

Then the first law for this open system is given by:

$$\frac{dE}{dt} = m_2(h_2 + \frac{V_2^{\ 2}}{2} + gz_2) - m_1(h_1 + \frac{V_1^{\ 2}}{2} + gz_1) + W - Q \tag{4.9}$$

where (dE/dt) is the rate at which the total energy of the system changes and 'g' is the acceleration due to gravity.

First law for open system in steady state

In steady state process, the time rate of change of all the quantities is zero, and mass is also conserved. As a result, the mass and total energy of the system do not change with time, hence, (dE/dt) is zero and from conservation of mass, $m_1 = m_2 = m$. Then the first law becomes:

$$(h_2 + \frac{V_2^{\ 2}}{2} + gz_2) - (h_1 + \frac{V_1^{\ 2}}{2} + gz_1) = \dot{q} - \dot{w} \tag{4.10}$$

where $\dot{q}$ and $\dot{w}$ are specific heat and work transfer rates

Second law of thermodynamics:

The second law of thermodynamics is a limit law. It gives the upper limit of efficiency of a system. The second law also acknowledges that processes follow in a certain direction but not in the opposite direction. It also defines the important property called entropy.

It is common sense that heat will not flow spontaneously from a body at lower temperature to a body at higher temperature. In order to transfer heat from lower temperature to higher temperature continuously (that is, to maintain the low temperature) a refrigeration system is needed which requires work input from external source. This is one of the principles of second law of thermodynamics, which is known as *Clausius statement of the second law.*

Clausius' statement of second law

It is impossible to transfer heat in a cyclic process from low temperature to high temperature without work from external source.

It is also a fact that all the energy supplied to a system as work can be dissipated as heat transfer. On the other hand, all the energy supplied as heat transfer cannot be continuously converted into work giving a thermal efficiency of 100 percent. Only a part of heat transfer at high temperature in a cyclic process can be converted into work, the remaining part has to be rejected to surroundings at lower temperature. If it were possible to obtain work continuously by heat transfer with a single heat source, then automobile will run by deriving energy from atmosphere at no cost. A hypothetical machine that can achieve it is called Perpetual Motion Machine of second kind. This fact is embedded in *Kelvin-Planck Statement of the Second law.*

Kelvin-Planck statement of second law

It is impossible to construct a device (engine) operating in a cycle that will produce no effect other than extraction of heat from a single reservoir and convert all of it into work.

Mathematically, Kelvin-Planck statement can be written as:

$$W_{cycle} \leq 0 \quad \text{(for a single reservoir)} \tag{4.11}$$

Reversible and Irreversible Processes

A process is reversible with respect to the system and surroundings if the system and the surroundings can be restored to their respective initial states by reversing the direction of the process, that is, by reversing the heat transfer and work transfer. The process is irreversible if it cannot fulfill this criterion.

If work is done in presence of friction, say by movement of piston in a cylinder then a part of the work is dissipated as heat and it cannot be fully recovered if the direction of process is reversed. Similarly, if heat is transferred through a temperature difference from higher temperature to a lower temperature, its direction cannot be reversed since heat transfer from lower temperature to higher temperature would require external work input. These are two examples of irreversible processes.

Reversible process is a hypothetical process in which work is done in absence of friction and heat transfer occurs isothermally. Irreversibility leads to loss in work output and loss in availability and useful work.

4.4.3. Heat engines, Refrigerators, Heat pumps:

A heat engine may be defined as a device that operates in a thermodynamic cycle and does a certain amount of net positive work through the transfer of heat from a high temperature body to a low temperature body. A steam power plant is an example of a heat engine.

A refrigerator may be defined as a device that operates in a thermodynamic cycle and transfers a certain amount of heat from a body at a lower temperature to a body at a higher temperature by consuming certain amount of external work. Domestic refrigerators and room air conditioners are the examples. In a refrigerator, the required output is the heat extracted from the low temperature body.

A heat pump is similar to a refrigerator, however, here the required output is the heat rejected to the high temperature body.

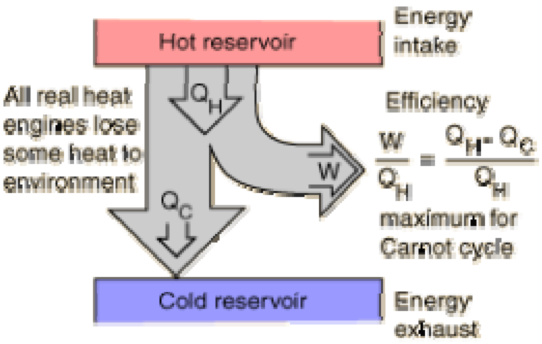
Carnot’s theorems for heat engines:

Theorem 1: *It is impossible to construct a heat engine that operates between two thermal reservoirs and is more efficient than a reversible engine operating between the same two reservoirs.*

Theorem 2: *All reversible heat engines operating between the same two thermal reservoirs have the same thermal efficiency.*

The two theorems can be proved by carrying out a thought experiment and with the help of second law. Carnot’s theorems can also be formed for refrigerators in a manner similar to heat engines.

Carnot efficiency: The Carnot efficiencies are the efficiencies of completely reversible cycles operating between two thermal reservoirs. According to Carnot’s theorems, for any given two thermal reservoirs, the Carnot efficiency represents the maximum possible efficiency.



Thermal efficiency for a heat engine, η_{HE} is defined as:

$$\eta_{HE} = \frac{W_{cycle}}{Q_H} = 1 - \frac{Q_C}{Q_H} \tag{4.12}$$

where W_{cycle} is the net work output, Q_C and Q_H and are the heat rejected to the low temperature reservoir and heat added (heat input) from the high temperature reservoir, respectively.

It follows from Carnot's theorems that for a reversible cycle ($\frac{Q_C}{Q_H}$) is a function of temperatures of the two reservoirs only. i.e. $\frac{Q_C}{Q_H} = \phi(T_{C,}T_H)$.

If we choose the absolute (*Kelvin)* temperature scale then:

$$\frac{Q_C}{Q_H} = \frac{T_C}{T_H} \tag{4.13}$$

$$\text{hence, } \eta_{Carnot,HE} = 1 - \frac{Q_C}{Q_H} = 1 - \frac{T_C}{T_H} \tag{4.14}$$

The efficiency of refrigerator and heat pump is called as Coefficient of Performance (COP). Similarly to heat engines, Carnot coefficient of performance for heat pump and refrigerators COP_{HP} and COP_R can be written as

$$\begin{aligned} COP_{Carnot,HP} &= \frac{Q_H}{W_{cycle}} = \frac{Q_H}{Q_H - Q_C} = \frac{T_H}{T_H - T_C} \\ COP_{Carnot,R} &= \frac{Q_C}{W_{cycle}} = \frac{Q_C}{Q_H - Q_C} = \frac{T_C}{T_H - T_C} \end{aligned} \tag{4.15}$$

where

W_{cycle} = work input to the reversible heat pump and refrigerator

Q_H = heat transferred between the system and the hot reservoir

Q_C = heat transferred between the system and cold reservoir

T_H = temperature of the hot reservoir

T_C = temperature of the cold reservoir

Clausius inequality:

The Clausius inequality is a mathematical form of second law of thermodynamics for a closed system undergoing a cyclic process. It is given by:

$$\oint \left(\frac{\delta Q}{T} \right)_b \leq 0 \tag{4.16}$$

In the above equation (4.16), δQ represents the heat transfer at a part of the system boundary during a portion of the cycle, and T is the absolute temperature at that part of the boundary. The subscript "b" serves as a reminder that the integrand is evaluated at the boundary of the system executing the cycle. The equality applies when there are no internal irreversibilities as the system executes the cycle, and inequality applies when there are internal irreversibilities are present.

Entropy:

As mentioned before, second law of thermodynamics introduces the property, entropy. It is a measure of amount of disorder in a system. It is also a measure of the extent to which the energy of a system is unavailable. From Clausius inequality, $\oint\left(\frac{\delta \mathrm{Q}}{\mathrm{T}}\right)_{\mathrm{b,rev}} = 0$ for a reversible cycle. This implies that the quantity $\left(\frac{\delta \mathrm{Q}}{\mathrm{T}}\right)_{\mathrm{b,rev}}$ must be a point function, hence a property of the system. This property is named as 'entropy' by Clausius. The entropy change between any two equilibrium states 1 and 2 of a system is given by:

$$S_2 - S_1 = \left(\int_1^2 \frac{\delta Q}{T}\right)_{\substack{\text{int}\\ rev}} \tag{4.17}$$

Where S_2, S_1 are the entropies at states 1 and 2. The subscript "int rev" is added as a reminder that the integration is carried out for any internally reversible process between the two states.

In general, for any process 1-2, the entropy change can be written as:

$$S_2 - S_1 \geq \left(\int_1^2 \frac{\delta Q}{T}\right)_b \tag{4.18}$$

The equality applies when there are no internal irreversibilities as the system executes the cycle, and inequality applies when there are internal irreversibilities are present.

Equation (4.18) can also be written as:

$$S_2 - S_1 = \left(\int_1^2 \frac{\delta Q}{T}\right)_b + \sigma \tag{4.19}$$

$$\text{where } \sigma : \begin{cases} > 0 & \textit{irreversibilities present within the system} \\ = 0 & \textit{no irreversibilities present within in the system} \end{cases}$$

The above equation may be considered as an entropy balance equation for a closed system. If the end states are fixed, the entropy change on the left side of Eqn. (4.19) can be evaluated independently of the details of the process. The two terms on the right side depend explicitly on the nature of the process and cannot be determines solely from the knowledge of end states. The first term on the right side of the equation is interpreted as *entropy transfer*. The direction of entropy transfer is same as that of heat transfer. The entropy change of a system is not accounted solely by the entropy transfer. We have to include another term for entropy generation due to internal irreversibililies in the system. The second term in Eqn. (4.19) accounts for this, and is interpreted as *entropy production.* The value of entropy production cannot be negative. It can have either zero or positive value. But the change in entropy of the system can be positive, negative, or zero.

$$S_2 - S_1 : \begin{cases} > 0 \\ = 0 \\ < 0 \end{cases} \tag{4.20}$$

Principle of increase of entropy:

According the definition of an isolated system one can write:

$$\Delta E_{isol} = 0 \tag{4.21}$$

because no energy transfers takes place across its boundary. Thus the energy of the isolated system remains constant.

An entropy balance for an isolated energy is written as:

$$\Delta S_{isol} = \left(\int_1^2 \frac{\delta Q}{T} \right)_b + \sigma_{isol} \tag{4.22}$$

Since there are there are no energy transfers in an isolated system, the first term in the above equation is zero, hence the above equation reduces to:

$$\Delta \mathrm{S}_{\mathrm{isol}} = \sigma_{\mathrm{isol}} > 0 \tag{4.23}$$

where σ_{isol} is the total amount of entropy produced within the isolated system, since this cannot be negative, it implies that the entropy of an isolated system can only increase. If we consider a combined system that includes the system and its surroundings, then the combined system becomes an isolated system. Then one can write:

$$\Delta \mathrm{S}_{\mathrm{system}} + \Delta \mathrm{S}_{\mathrm{surroundings}} = \sigma_{\mathrm{isol}} > 0 \tag{4.24}$$

since entropy is produced in all actual processes, only processes that can occur are those for which the entropy of the isolated system increases. Energy of an isolated system is conserved whereas entropy of an isolated system increases. This is called the *principle of increase of entropy.*

Third law of thermodynamics:

This law gives the definition of absolute value of entropy and also states that absolute zero cannot be achieved. Another version of this law is that “the entropy of perfect crystals is zero at absolute zero”. This statement is attributed to Plank. This is in line with the concept that entropy is a measure of disorder of the system. If ‘ω’ is the probability of achieving a particular state out of a large number of states; then entropy of the system is equal to $\ln(\omega)$. The transitional movement of molecules ceases at absolute zero and position of atoms can be uniquely specified. In addition, if we have a perfect crystal, then all of its atoms are alike and their positions can be interchanged without changing the state. The probability of this state is unity, that is $\omega = 1$ and $\ln(\omega) = \ln(1) = 0$

For imperfect crystals however there is some entropy associated with configuration of molecules and atoms even when all motions cease, hence the entropy in this case does not tend to zero as $T \rightarrow 0$, but it tends to a constant called the entropy of configuration.

The third law allows absolute entropy to be determined with zero entropy at absolute zero as the reference state. In refrigeration systems we deal with entropy changes only, the absolute entropy is not of much use. Therefore entropy may be taken to be zero or a constant at any suitably chosen reference state.

Another consequence of third law is that absolute zero cannot be achieved. One tries to approach absolute zero by magnetization to align the molecules. This is followed by cooling and then demagnetization, which extracts energy from the substance and reduces its temperature. It can be shown that this process will require infinite number of cycles to achieve absolute zero. In a later chapter it will be shown that infinitely large amount of work is required to maintain absolute zero if at all it can be achieved.

Questions:

1. a) Prove the equivalence of Clausius and Kelvin statements. (Solution)

   b) Explain briefly about Carnot's corollaries? (Solution)

2. Divide the following in to a) point function and path function and b) extensive property and intensive property.

   Pressure, enthalpy, volume, temperature, specific volume, internal energy, work, heat, entropy, pressure, density, mass, and specific heat. (Solution)

3. Gases enter the adiabatic converging nozzle of an aircraft with velocity V_1 from combustion chamber. Find out the expression for the change in enthalpy between inlet and outlet of the nozzle, where inlet area A_1 and outlet area A_2 ($A_2 < A_1$) are given and the nozzle is assumed to be horizontal. (Solution)

4. 10 kW of electrical power input is given to a mechanical pump, which is pumping water from a well of depth 10 m. Pump is heated up because of frictional losses in the pump. In steady state, pump temperature is $T_M = 40^oC$ and the surroundings is at $T_S = 20^oC$. The convective heat transfer between the motor surface area A_M ($= 0.8\ m^2$) and the surroundings air is governed by

$$Q = hA_M(T_M - T_S)$$

Where $h = 0.15\ kW/m^2\text{-}K$, is a convective heat transfer coefficient between the motor surface and the surrounding air. Find out the maximum mass flow rate of the water that mechanical pump can pump? (Solution)

5. A refrigerator manufactured by one manufacturing company works between 40^oC and -5^oC. The manufacturer claims that coefficient of performance of that refrigerator is 7.0. Do you agree with his statement? Justify your answer. (Solution)

6. 2 kg of ice at -10 ^{o}C and 3 kg of water at 70 ^{o}C are mixed in an insulated container. Find a) Equilibrium temperature of the system b) Entropy produced. $(C_{ice} = 2.0934 kJ/kg - K,\ L_{fusion} = 334.944 kJ/kg,\ C_{water} = 4.1868 kJ/kg - K)$ (Solution)

7. Answer the following true or false and justify your answer.

a) Change in the entropy of a closed system is the same for every process between two given states. (Answer)

b) The entropy of a fixed amount of an incompressible substance increases in every process in which temperature decreases. (Answer)

c) Entropy change of a system can become negative. (Answer)

d) Entropy change of an isolated system can become negative. (Answer)

e) A process which violates second law of thermodynamics also violates the first law of thermodynamics. (Answer)

f) When a net amount of work is done on a closed system undergoing an internally reversible process, a net heat transfer from the system has to occur. (Answer)

g) A closed system can experience an increase in entropy only when irreversibilities are present within the system during the process. (Answer)

h) In an adiabatic and internally reversible process of a closed system, the entropy remains constant. (Answer)

i) No process is allowed in which the entropies of both the system and the surroundings increase. (Answer)

j) During a process the entropy of the system might decrease while the entropy of surroundings increase and conversely. (Answer)

k) The value of coefficient of performance of heat pump is one greater than that of refrigerator. (Answer)