

## Syllabus:

1- Fundamental concepts and definitions.
2- The first law of thermodynamics and non flow processes.
3- The working fluid.
4- Reversible and irreversible processes.
5- The second law of thermodynamics (Entropy).
6- Ideal gas cycles.
7- The steam plant-vapor cycles.
8 - Gas mixtures.
9 - The combustion.

## Recommended Books:

1- Applied Thermodynamics, by T.D. Eastop and A.McConkey, third edition.

## Chapter One

## Fundamental Concept and Definitions

Thermodynamics:-_ is the science of the relationship between heat, work and the properties of systems. It is concerned with the means necessary to convert heat energy from available sources such as chemical fuels or nuclear piles, into mechanical work.

System:- may be defined as a collection of matter within prescribed and identifiable boundaries.

Surroundings:- The mass or region outside the system.
Boundary:- is the real or imaginary surface that separates the system from its surroundings.

## Surroundings

Boundary

## System

Note:- The boundary of a system can be fixed or movable, mathematically speaking, the boundary has zero thickness, and thus it can neither contain any mass nor occupy any volume in space.
**: there are three type of system.
1- Closed system (control mass):- is a system of a fixed a mount of mass, and no mass can cross its boundary. That is, no mass can enter or leave a closed system, as shown in figure below. But energy in the form of heat or work can cross the boundary.


2-Open system (control volume):- is a system in which both mass and energy can cross the boundary of control volume, which is called a control surface. As shown in figure below (as an example of an open system, compressor, turbine and nozzle).


3-Isolated system:- A system that does not interact with the surrounding, i.e. no heat transfer across system boundary.

## Units:-

(1) Length ( $m$ )
(4) Temperature ( $K$ )
(2) Mass (kg)
(5) Electric current (A)
(3) Time ( $s$ )
(6) Luminous intensity (Candela, $C d$ )

For example:
velocity $=\frac{\text { length }}{\text { time }}=\frac{m}{s}, \quad$ acceleration $=\frac{\text { velocity }}{\text { time }}=\frac{m}{s^{2}}, \quad$ specificvolume $=\frac{\text { volume }}{\text { mass }}=\frac{m^{3}}{k g}$
$\qquad$ In order to deal with the subject of applied thermodynamics rigorously it is necessary to define the concepts used.

Heat:- is a form of energy which is transferred from one body to another body at a lower temperature.


Pressure $(p)$ :- is the force exerted by the system on unit area of its boundaries. Units of pressure $\left(N / m^{2}\right),(P a)$.
pressure $=\frac{\text { force }}{\text { area }}=\frac{F}{A}$
$k P a=10^{3} \mathrm{~Pa}$
1 bar $=10^{5} \mathrm{~Pa}$
$\mathrm{MPa}=10^{6} \mathrm{~Pa}$

Surroundings
(a)

Surroundings


Surtoundings

**: Absolute pressure $=$ atmospheric pressure + gauge pressure
**:Vacuum pressure $=$ atmospheric pressure - gauge pressure
Volume (V): is the space occupied by a substance, and is measured in $\left(m^{3}\right)$.
Specific volume ( $\boldsymbol{v}$ ): is the space occupied by unit mass of a substance and is measured in $\left(\mathrm{m}^{3} / \mathrm{kg}\right)$.

Density ( $\rho$ ): is the mass of substance per unit volume, and is measured in $\left(\mathrm{kg} / \mathrm{m}^{3}\right)$.
$\rho=\frac{m}{V}, \quad v=\frac{V}{m}, \quad v=\frac{1}{\rho}$
Temperature (T): is the measure of hotness or coldness. The variation of property of any substance with temperature can be used to provide a temperature measuring instrument.
**: Absolute temperature, $\mathrm{T}(\mathrm{K})=\mathrm{T}\left({ }^{\circ} \mathrm{C}\right)+273$
$\mathrm{T}(\mathrm{F})=(9 / 5) \mathrm{T}\left({ }^{\circ} \mathrm{C}\right)+32$

$$
\text { Ice point: } \quad 0^{\circ} \mathrm{C} \quad 273 \mathrm{~K} \quad 32 \mathrm{~F}
$$

$$
\text { Steam point : } 100^{\circ} \mathrm{C} \quad 373 \mathrm{~K} \quad 212 \mathrm{~F}
$$

$$
\text { Absolute zero : }-273^{\circ} \mathrm{C} \quad \text { 〇K } \quad-459.4
$$

Force ( $\mathbf{F}$ ): Newton's second law be written as
$F \propto m^{*} a$
Where:
$m$ : is the mass of a body ( kg ).
$a$ : the acceleration $\left(\mathrm{m} / \mathrm{s}^{2}\right)$.
$F=K m a$
In SI unit, $K=1$


Energy: is the capacity of doing work and is measured in (N.m), (J).

## Types of energy:

1-Potential energy: This is the energy due to the position of mass in the gravitational field at the earth.

$$
\text { P.E. }=m g Z
$$

2-Kinetic energy: This is due to the motion of substance.
K.E. $=(1 / 2) m C^{2}$

3-Internal energy: It is the energy arising due to the motion and position of the internal particles (atoms or molecules) of matter.

All fluid store energy. The store of energy within any fluid can be increased or decreased as a result of various processes carried out on or by the fluid. The energy
stored within the fluid which results from the internal motion of its atoms and molecules is called its internal energy.

4-Chemical energy: is energy released due to changes in chemical composition.
5-Atomic energy: is energy released due to changes in atomic structure, such as nuclear fission.

Power: is defined as the rate of doing work. The standard unit of power is the watt ( $W$ ).
$1 \mathrm{~W}=1 \mathrm{~J} / \mathrm{s}=1 \mathrm{~N} . \mathrm{m} / \mathrm{s}$
Work: is defined as the product of a force and the distance moved in the direction of the force.

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Work=F* *
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**: Note: If work done by the system (+ve)
If work done on the system (-ve)

## The state of the working fluid:-

The state: is the condition or position which is defined in term of properties. The important properties in thermodynamics are pressure, temperature, specific volume, internal energy, enthalpy and entropy.

Working fluid: is the matter contained within the boundaries of the system can be liquid, vapor or gas. e.g. steam in steam engines, air and fuel mixtures in internal combustion engines and (ammonia, freons) in refrigeration machines.

Process: it is the transformation of system from one state equilibrium to another.
The state: it is a condition of the system as described or measured by the properties. The state of a pure substance is determined by any two of its independent properties.

Cycle: A cycle is a sequence of processes which returns the system to its initial state.
Path of process: it's the continuous sequence of equilibrium states between initial and final states.

(a)

(b)

(c)

## Reversibility:



Reversibility process: when a system changes state in such a way that at any instant during the process the state point can be located on the diagram then the process is said to be reversible.

When a fluid undergoes a reversible process, both the fluid and its surrounding can always be restored to their original state. (or) the process passes through a continuous series of equilibrium states.

Irreversibility process: A process cannot be kept in equilibrium in its intermediate states and a continuous path cannot be traced on a diagram of properties.

(a)
(a) Reversible process

(b) Irreversible process

## Reversible work:-

The work done by the fluid, $d W=F d L$
$d W=p A d L=p d V$

considering unit $m$ :

## Work done $=$ pd $v$

when a reversible process take place between state 1 and state 2 .

Work done by unit mass of fluid $=\int^{2} p d v$

Work done $=$ shaded area $=\int_{v 1}^{v 2} p d v$


## Example 1.1

A fluid at a pressure of 3 bar , and with specific volume of $0.18 \mathrm{~m}^{3} / \mathrm{kg}$, contained in a cylinder behind a piston expands reversibly to a pressure of 0.6 bar according to a law, $p=c / v^{2}$. Where $c$ is a constant. Calculate the work done during the process.

## Solution:

$\mathrm{P}_{1}=3$ bar, $\mathrm{v}_{1}=0.18 \mathrm{~m}^{3} / \mathrm{kg}, \mathrm{p}_{2}=0.6 \mathrm{bar}, \mathrm{p}^{2}=c, W=$ ?
$W_{1 \rightarrow 2}=\int_{1}^{2} p d v=\int_{v_{1}}^{v_{2}} \frac{c}{v^{2}} d v=c \int_{v_{1}}^{v_{2}} \frac{d v}{v^{2}}$
$c=p_{1} \mathrm{v}_{1}^{2}=p_{2} \mathrm{v}_{2}^{2}$
$v_{2}^{2}=v_{1}^{2}\left(\frac{p_{1}}{p_{2}}\right)$

$v_{2}=\sqrt{v_{1}^{2}\left(\frac{p_{1}}{p_{2}}\right)}=\sqrt{(0.18)^{2}\left(\frac{3}{0.6}\right)}=0.402 \mathrm{~m}^{3} / \mathrm{kg}$
$W_{1 \rightarrow 2}=p_{1} v_{1}^{2} \int_{v_{1}}^{v_{2}} \frac{d v}{v^{2}}=p_{1} v_{1}^{2}\left[\frac{v^{-1}}{-1}\right]_{v_{1}}^{v_{2}}=p_{1} v_{1}^{2}\left[\frac{1}{v_{1}}-\frac{1}{v_{2}}\right]$
$W_{1 \rightarrow 2} 3 * 10^{5}(0.18)^{2}\left[\frac{1}{0.18}-\frac{1}{0.402}\right]=29820.9 \frac{\mathrm{~N} . \mathrm{m}}{\mathrm{kg}}=29.8 \mathrm{~kJ} / \mathrm{kg}$

The work done by the fluid Note: for compression process
$W_{1 \rightarrow 2}=\int_{1}^{2} p d v=\int_{v_{1}}^{v_{2}} p d v=(-)$
The work done on the fluid


Note: when a fluid undergoes a series of a processes and finally returns to its initial state, then it is said to have undergone a thermodynamic cycle.

If the process $1 \rightarrow 2$ and $2 \rightarrow 3$ and $3 \rightarrow 4$ and $4 \rightarrow 1$ are reversible process then the cycle is called reversible cycle.


## Example 1.2

Unit mass of a certain fluid is contained in a cylinder at an initial pressure of 20 bar. The fluid is allowed to expend reversibly behind a piston according to a law $p V 2=$ constant until the volume is doubled. The fluid is then cooled reversibly at constant pressure until the piston regains its original position; heat is then supplied reversibly with the piston firmly locked in position until the pressure rises to the original value of 20 bar. Calculate the net work done by the fluid, for an initial volume of $0.05 \mathrm{~m}^{3}$.

## solution:

The total work done (net work done) $=W_{l \rightarrow 2}+W_{l \rightarrow 3}+W_{3 \rightarrow 1}$
$W_{1 \rightarrow 2}=\int_{1}^{2} p d v=\int_{v_{1}}^{v_{2}} \frac{c}{v^{2}} d v=c \int_{v_{1}}^{v_{2}} \frac{d v}{v^{2}}$
$W_{1 \rightarrow 2}=p_{1} v_{1}^{2} \int_{v_{1}}^{v_{2}} \frac{d v}{v^{2}}=p_{1} v_{1}^{2}\left[\frac{v^{-1}}{-1}\right]_{v_{1}}^{v_{2}}=p_{1} v_{1}^{2}\left[\frac{1}{v_{1}}-\frac{1}{v_{2}}\right]$
$W_{1 \rightarrow 2}=20 * 10^{5}(0.05)^{2}\left[\frac{1}{0.05}-\frac{1}{0.1}\right]=50000 N . m=50 k$
$W_{2 \rightarrow 3}=\int_{V_{2}}^{V_{3}} p d V=p \int_{V_{2}}^{V_{3}} d V=p_{2}[V]_{V_{2}}^{V_{3}}=p_{2}\left(V_{3}-V_{2}{ }^{\prime}\right.$,

$p_{1} V_{1}^{2}=p_{2} V_{2}^{2}$

$$
p_{2}=p_{1}\left(\frac{V_{1}}{V_{2}}\right)^{2}=20\left(\frac{0.05}{0.1}\right)^{2}=5 \mathrm{bar}
$$

$$
W_{2 \rightarrow 3}=5 * 10^{5}(0.05-0.1)=-25000 \text { N. } m=-25 \mathrm{~kJ}
$$

$$
W_{3 \rightarrow 1}=\int_{V_{3}}^{V_{1}} p d V=0
$$

The total work $=50-25+0=25 k J$

## H.W:

1 kg of a fluid is compressed according to a law $\mathrm{p} v=0.25$ where p is in bar and $v$ $\mathrm{m}^{3} / \mathrm{kg}$. The final volume is $(1 / 4)$ of the initial volume. Calculate the work done on the fluid.

