**4. FIRST LAW OF THERMODYNAMICS**

**PROPERTIES OF GAS MIXTURES:**

|  |  |
| --- | --- |
| Change in Properties for Thermodynamic **Cycle** is zero. | E.g. |

**STATEMENT OF FIRST LAW (FOR CYCLE):**

|  |  |
| --- | --- |
| When System is undergoing cycle, net heat transfer is equal to net-work transfer. | & |

This is valid for reversible and irreversible cycles.

**FIRST LAW (FOR A NON-FLOW PROCESS):**

|  |  |
| --- | --- |
| For Cycle, , Where Energy | For Process, Non-Flow Energy Eq. => |

This is valid for reversible and irreversible cycles.

|  |  |
| --- | --- |
| Non-Flow Energy Eq. (N.F.E.E.) For Closed System and Reversible Process. |  |
| N.F.E.E. For isolated System, |  |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **TYPE OF ENERGY** | | | | |
| TRANSIT ENERGY | | STORED ENERGY | | |
| HEAT | WORK | MICROSCOPIC | MACROSCOPIC | |
|  |  | Small or Molecular Level | Large or Bulk | |
|  |  | INTERNAL | KE: Due to Velocity | PE: Due to Elevation |

**INTERNAL ENERGY:** It’s energy associated with molecules. It includes,

|  |  |  |
| --- | --- | --- |
| Translational K.E. | Rotational K.E. | Vibrational K.E. |

|  |  |
| --- | --- |
| **INTERNAL ENERGY (U)** | **INTERNAL ENERGY ()** |
| It’s Extensive Property. | It’s intensive property (Independent of mass) |

**TOTAL ENERGY OF SYSTEM (E):**

|  |  |
| --- | --- |
|  | Here, |

**FIRST LAW (AFTER NEGLECTING K.E. & P.E.):**

|  |  |
| --- | --- |
| For Reversible and Irreversible process: | For Reversible process: |

**JOULE’S LAW:** “For an ideal Gas internal energy is function of temperature only” ()

|  |  |  |
| --- | --- | --- |
| For Supply : increases. | For Rejecting : decreases. | For : remains constant. |

|  |  |
| --- | --- |
| **ENTHALPY (H)** | **SPECIFIC ENTHALPY (h)** |
|  |  |
| Where, Total internal Energy (KJ)  Pressure (KPa)  Total Volume (m3) | Where Specific internal Energy ()  Pressure (KPa)  Total Volume () |
| It’s Extensive Property. | It’s intensive property (Independent of mass) |

|  |  |
| --- | --- |
| **SPECIFIC HEAT AT CONSTANT VOLUME** | **SPECIFIC HEAT AT CONSTANT PRESSURE** |
|  |  |
| For ideal Gas,   |  |  | | --- | --- | |  |  | | For ideal Gas,   |  |  | | --- | --- | |  |  | |
| **Molar Specific Heat at Constant Volume:** | **Molar Specific Heat at Constant Pressure:** |
| **Molar Internal Energy Change:** | **Molar Enthalpy Change:** |

“For an ideal Gas Enthalpy is function of temperature only” ()

|  |  |  |
| --- | --- | --- |
| For Increase : increases. | For Decrease : Decreases. | For : remains constant. |

**IDEAL GAS RELATION:** From

|  |  |  |  |
| --- | --- | --- | --- |
|  |  |  |  |

**MOLAR IDEAL GAS RELATION:**

|  |  |  |  |
| --- | --- | --- | --- |
|  |  |  |  |

* For Ideal Gas Depends only on molecular structure.
* For Ideal Gas Specific Heats () depends on molecular weights and molecular structure.

|  |  |
| --- | --- |
|  |  |

**HEAT TRANSFER EQUATIONS IN NON-FLOW PROCESS:**

|  |  |  |
| --- | --- | --- |
| **PROCESS** | **EQUATIONS ()** | **FOR IDEAL GAS,** |
| Isochoric Process |  |  |
| Isobaric Process (Reversible) |  |  |
| Isothermal Process |  |  |
| Adiabatic Process () | It indicates Work done by/on the system is due to change in U. | |
| Polytropic Process |  | & Eq. |

|  |  |
| --- | --- |
| **POLYTROPIC SPECIFIC HEAT ():** |  |

**DERIVATION OF FOR REVERSIBLE ADIABATIC PROCESS:**

|  |  |
| --- | --- |
| Here For the process,  & | By Derivation of enthalpy we will obtain form both equations, |

**γ VALUES FOR VARIOUS GASES:**

|  |  |
| --- | --- |
| From the physics:  Here,  From the enthalpy equation, | Here, Internal Energy (),  Characteristic Gas Constant (),  Absolute temperature (),  Degrees of freedom, |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Type of Gas** | **Translational DOF** | **Rotational DOF** | **Total DOF** |  |  |  |
| Mono-Atomic Gas (He, Ar) | 3 | 0 | 3 |  |  | 1.67 |
| Di-Atomic () | 3 | 2 | 5 |  |  | 1.4 |
| Poly Atomic () | 3 | 3 | 6 |  |  | 1.33 |

**APPLICATION OF FIRST LAW:**

|  |  |
| --- | --- |
| **FREE EXPANSION PROCESS:** Expansion of gas against vacuum., | Note:   1. Insulated chamber. 2. No Resistance from vacuum. |
| **IDEAL GAS FREE EXPANSION:**  It’s irreversible isothermal Process. The temperature is initially dropping after again reaches to the initial temp. |  |

**PERPETUAL MOTION MACHINE OF FIRST KIND (PMM-I):**

|  |  |
| --- | --- |
| There is a machine which is producing work continuously without taking any input energy. It’s impossible because it violates first law of thermodynamics. | Perpetual = Continuous |

**CHANGE IN INTERNAL ENERGY OF SOLID AND LIQUIDS:**

|  |  |
| --- | --- |
| For solid and liquids, | Hence, |

**SPECIFIC HEAT & CHARACTERISTIC GAS CONSTANT FOR GAS MIXTURE:**

|  |  |  |
| --- | --- | --- |
|  |  |  |
|  |  |  |

**DALTON’S LAW OF PARTIAL PRESSURE:**

|  |
| --- |
| Ideal Gas () + Ideal Gas () = Ideal Gas () |

**RELATION BETWEEN MOLE FRACTION & PRESSURE FRACTION FROM DALTON’S LAW:**

|  |
| --- |
|  |

**HEAT TRANSFER TO THE GAS MIXTURES:**

|  |  |  |
| --- | --- | --- |
| **Isochoric Process** | Where, & |  |
| **Isobaric Process** |  |  |
| **Adiabatic Mixing of Ideal Gas in Rigid Tank** | Where, & |  |

**VANDER WALL’S EQUATION:** It’s Actual/ Real Gas Equation.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| For Actual Gas, we can’t ignore intermolecular force and volume of gas,  Where, =Inter molecular Forces, Volume of Molecules.   |  |  |  | | --- | --- | --- | | **Units:** |  |  | | For Ideal Gas:   1. Intermolecular Force 2. Volume of Gas Molecules   Ideal Gas Eq.: |

**FIRST LAW FOR OPEN SYSTEM:**

|  |  |
| --- | --- |
| **OPEN SYSTEM:** Mass & Energy Transfer Allowed. | **CONTROL VOLUME:** It’s Volume of open system. |
| **CONTROL SURFACE:** Imaginary surface separates open system and surroundings. | |
| **STEADY FLOW PROCESS:** Fluid properties don’t change with respect to time at a given location.   |  |  |  | | --- | --- | --- | | Mass Balance: | Energy Balance: | Energy & Mass inside always remains constant. | | |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **CONTINUITY EQUATION:** |  |  | For Incompressible fluid, |  |

**FLOW WORK:** The work associated with flowing fluid. & .

**STEADY FLOW ENERGY EQUATION:**

|  |  |  |  |
| --- | --- | --- | --- |
|  | Supplied heat ,  Work Done by the System   |  |  | | --- | --- | |  |  | |

1. S.F.E.E. is valid for reversible and irreversible process.

**Units of S.F.E.E.:**

|  |  |  |  |
| --- | --- | --- | --- |
|  |  | Velocity ()  Elevation () | () |
| or |  |  |  |

**EXAMPLES OF STEADY FLOW/OPEN SYSTEM PROCESS:**

|  |  |  |  |
| --- | --- | --- | --- |
| **TURBINE:**   |  |  | | --- | --- | |  |  |   Here,  It’s Work Producing Device. | NOTE:   1. KE & PE are negligible compared to Enthalpy. 2. Turbine is insulated. . |
| **IC ENGINE:**   |  |  | | --- | --- | |  |  |   Here,  It’s Work Producing Device. | NOTE:   1. KE & PE are negligible compared to Enthalpy.   If IC Engine is insulated. . |
| **ROTARY/ RECIPROCATING COMPRESSOR:**   |  |  | | --- | --- | |  |  |   Here,  It’s Work Consuming Device. | NOTE:   1. KE & PE change are negligible compared to Enthalpy. 2. Compressor is insulated. . |

|  |  |
| --- | --- |
| **FLOW WORK** | **CONTROL VOLUME WORK** |
| Work done by control volume is zero. | Work done by control volume is not equal to zero. |
| It just works required to flow of liquid. | It’s the work done by the system it includes flow work. |

**NON-WORK DEVICES:**

|  |  |
| --- | --- |
| **DEVICES** | **NOTES** |
| **PIPELINE:**  **Special Case of Pipeline:** Electric heater is inserted inside pipeline. | 1. (Pipeline is not doing any work) 2. (Cross section area is same) 3. (Pipeline is horizontal) |
| **NOZZLE:** | 1. (Nozzle is not doing any work) 2. (Cross section area isn’t same) 3. (Nozzle is horizontal) 4. Nozzle is insulated. . |
| **DIFFUSER:** | 1. (Diffuser is not doing any work) 2. (Cross section area isn’t same) 3. (Diffuser is horizontal) 4. Diffuser is insulated. . |

**MULTI STREAMS DEVICES:**

|  |  |
| --- | --- |
| **DEVICES** | **NOTES** |
| **HEAT EXCHANGER:**  Mass Balance:   |  |  | | --- | --- | |  |  | |  | |   By SFEE (in ), | 1. (HE is not doing any work) 2. HE is insulated. . 3. KE & PE are negligible compared to Enthalpy. |
|  | 1. If we consider heat loss |

**FLOW WORK IN EVACUATED BOTTLE:**

|  |  |
| --- | --- |
|  | 1. This is not expansion case. |

**THROTTLING PROCESS:** It’s flow of fluid through a small passage.

|  |  |
| --- | --- |
| At Partially opening of valve,  By Appling S.F.E.E.,  Hence, It’s **Isenthalpic process. Here, pressure decreases. (according to Bernoulli’s equation)** | 1. KE & PE change are negligible compared to Enthalpy. 2. Throttling heat transfer . ( Area for )   In throat, Pressure decrease, Area decrease, Velocity increase. |
| **NOZZLE** | **THROTTLING** |
| C/s Area Gradually decreases. | Drastically C/s area decreases. It’s irreversible process (Due to molecular friction at sudden reducing C/s). |

Throttling is irreversible adiabatic () process.

**JOULE-THOMSON:**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **COEFFICIENT ():**  It’s defined as ratio of change in temperature to the change in pressure at constant enthalpy. | **EXPERIMENT:** Throttling valve and section both sides.   |  |  | | --- | --- | | Initially Valve is fully open | At partially closing successively | | At A: | At B: |   **PLOTTED GRAPH:** T-P Diagram.  **OBSERVATION:** Pressure decreases with increasing in temp. and reaches maximum. If Further Pressure decreases, temp. decreases. | |  |
| **ISENTHALPIC CURVE:** Enthalpy remains constant. | | **INVERSION CURVE:** (Slop of T-P dia.)line. | |

**SIGNIFICANCE OF ():** Joule-Thomson coefficient represents slope of isenthalpic line on T-P diagram.

|  |  |  |
| --- | --- | --- |
| LHS of Inversion Curve:  **(Cooling)** | RHS of Inversion Curve:  **(Heating)** | On of Inversion Curve:  **Temperature remains constant.** |
| Temperature during throttling of **Gas** may increase, decrease or may remain constant. | | |

**OPEN SYSTEM WORK TRANSFER:**

|  |  |
| --- | --- |
| **N. F. E. E.** | **S. F. E. E.** |
|  |  |

**OPEN SYSTEM REVERSIBLE WORK TRANSFER:**

|  |  |
| --- | --- |
| Take Example of IC engine and consider it as both Open system and closed system as reversible process,  By ignoring K.E., P.E. in S.F.E.E, | From N.F.E.E.,  By Equating both equation we can get, |

* The Area under the curve when projected to pressure axis represents open system reversible work transfer.

**WORK TRANSFER IN VARIOUS FLOW PROCESS:**

|  |  |  |  |
| --- | --- | --- | --- |
| **Isochoric Process** |  | |  |
| **Isobaric Process** |  | |  |
| **Iso Thermal Process** |  | |  |
| **Adiabatic Process** |  | |  |
| **Polytropic Process** |  | |  |
| **Isothermal Open System** | | **Isothermal Close System** | |
|  | |  | |
|  | | | |

**UNSTEADY FLOW PROCESS:**

**UNSTEADY FLOW:**

Fluid properties change with respect to time at a given location. So, mass and energy get stored in the control volume.

**NOTATIONS:**

|  |  |  |  |
| --- | --- | --- | --- |
| = Inlet Mass | = Exit Mass | = Initial Mass in the C.V. | = Final Mass in the C.V. |
| = Inlet Energy | = Exit Energy | = Initial Energy in the C.V. | = Final Energy in the C.V. |

|  |  |
| --- | --- |
| **MASS BALANCE:** | **ENERGY BALANCE:** |

Here, for the process if C.V. is consuming heat and developing work,

|  |  |
| --- | --- |
| By neglecting K.E. & P.E., | By neglecting K.E. & P.E., |

Here,

|  |  |
| --- | --- |
|  | Here, don't change w. r. t. time, |

**EXAMPLES OF UNSTEADY FLOW PROCESS:**

|  |  |
| --- | --- |
| **CHARGING OF TANK/ TANK FILLING PROCESS** | **DISCHARGING OF TANK** |