Thermodynamics and Energy Conversion (EN 203) – Autumn 2020-21

Problem Set -2

First Law of Thermodynamics

1. **Properties of pure substance**

   The properties of a certain pure substance are given as follows:

   $u = 196 + 0.718\ t$ and $pv = 287(t+273)$, where u is the specific internal energy in kJ/kg, t is the temperature in ^{o}C, p is the pressure in N/m^2 and v is the specific volume in m^3/kg. Find c_v and c_p for this substance.

2. **Work done at constant pressure**

   A pure substance is contained in a cylinder closed by a piston. A stirrer, rotated by means of a shaft protruding through the cylinder end plate, causes the substance to undergo adiabatically a fully resisted constant pressure expansion process as the piston moves outward slowly. Show that the shaft work (stirrer work) done on the system is equal to the increase in enthalpy of the substance.

3. **Processes in constant volume system**

   A system consisting of a mixture of air and gasoline at an initial temperature of 15 ^{o}C is contained in a rigid vessel. The following processes occur in sequence: (i) the mixture is heated to 200 ^{o}C by a heat transfer of 3.0 kJ; (ii) The mixture is then ignited by a minute spark which causes the mixture to burn completely. This process is adiabatic and the final temperature is 1450 ^{o}C. (iii) The products of combustion are cooled to 120 ^{o}C by heat transfer of 32 kJ. Evaluate the energy of the contents of the vessel after each of the above three process, assuming the initial energy of the system to be 10 kJ.

4. **Processes in piston-cylinder system**

   An equal mass of the same mixture in Question#3 is contained in a cylinder closed by a piston. The following processes occur in sequence: (i) adiabatic compression to a temperature 200 ^{o}C; (ii) adiabatic complete combustion at constant volume; (iii) expansion to a temperature of 120 ^{o}C, the work done by the system being 31 kJ and (iv) cooling at constant volume until the temperature reaches 15 ^{o}C. On the assumption that the energy of the system depends only upon its temperature and chemical aggregation, evaluate the work done during process (i) and the heat transfer during process (iii). Also, explain whether or not the system has executed a thermodynamic cycle.

5. **Cyclic process**

   A certain mass of air entrapped in a piston-cylinder device is first compressed. The work done on the air during this process is 82 kJ and the heat transferred out is 45 kJ. The air then brought back to its initial state by an expansion process. If the work output during this process is 10 kJ, find the magnitude and direction of the heat transfer during this process.

6. Cyclic process

A system comprises a certain mass of gas is heated at constant volume. The heat transfer is 200 kJ. The gas is then cooled at constant pressure during which heat transferred out is 70 kJ and the work done on it is 50 kJ. If the system is then restored to its initial state through an adiabatic process, find the magnitude and direction of work during this adiabatic process.

7. Steady state situation

A fluid flows steadily through a rotary device. For a kilogram of fluid, the heat transfer out of the device is 24 kJ. The fluid properties at the entry are 5 bar, 227 °C, 50 m/s and 0.78 m^3/kg. The corresponding properties at exit are 1 bar, 57 °C, 100 m/s and 0.97 m^3/kg. The inlet manifold is 5 m above the exit manifold. For the fluid, the internal energy is a function of temperature only and this its $c_v = 0.7$ kJ/kg K. Find the work output in kJ/kg.

8. Steady state process in turbine

Steam flows into a turbine, at a flow rate of 5000 kg/h. The turbine develops a power of 550 kW. The heat loss from the casing and the bearing is negligible. (a) Find the change in enthalpy across the turbine, if the inlet velocity is negligible and the exit velocity is 360 m/s and the change in potential energy is negligible. (b) Find the change in enthalpy across the turbine, if the inlet velocity is 66 m/s (exit velocity being same as given above) and the inlet pipe is 3 m above the exit pipe.

9. Mixing of substances and work done

Two air streams A ($\dot{m}_A = 0.8$ kg/s, $p_A = 15$ bar and $t_A = 250$□) and B ($\dot{m}_B = 0.5$ kg/s, $p_B = 15$ bar and $t_B = 200$ °C) are mixed in a large chamber supplies the mixed air, at 10 bar, to a turbine. The turbine exhausts the air at 30 °C to the atmosphere. Assume steady adiabatic flow all through. Neglect kinetic and potential energy. Assume that enthalpy and internal energy of the air are function of temperature only and that $c_p = 1$ kJ/kg K and $c_v = 0.718$ kJ/kg K. Determine (a) the temperature of air at inlet to the turbine and (b) the power developed by the turbine.

10. Flow

Steam enters a rotary turbine steadily through an inlet pipe of 15 cm diameter at a rate of 4000 kg/h. The specific volume at the entry is 0.285 m^3/kg. The exit pipe diameter is 25 cm and the specific volume of the steam at exit is 15.0 m^3/kg. Find the inlet and exit velocity.

- End of Document -