بِسْمِ اللَّهِ الرَّحْمَٰنِ الرَّحِيمِ

Applied Thermodynamics

Week_08

Instructor: Mr. Adnan Qamar

Mechanical Engineering Department

Reversible and Irreversible Processes

Constant Volume Process:

In a constant volume process the working substance is contained in a rigid vessel, hence the boundaries of the system are immovable, and no work can be done on or by the system. It will be assumed that 'constant volume' implies zero work unless stated otherwise. From the non-flow energy equation, for unit mass,

$$Q + W = u_2 - u_1$$

Since no work is done, we therefore have

$$Q = u_2 - u_1 \rightarrow (1)$$

or for mass, m, of the working substance

$$Q = U_2 - U_1 \rightarrow (2)$$

Reversible and Irreversible Processes

Constant Volume Process:

> All the heat supplied in a constant volume process goes to increasing the internal energy.

> A constant volume process for a vapour is shown on a *p-v diagram in Fig. 3.1 (a). The initial and final states have been chosen to be in the wet region and superheat region respectively.*

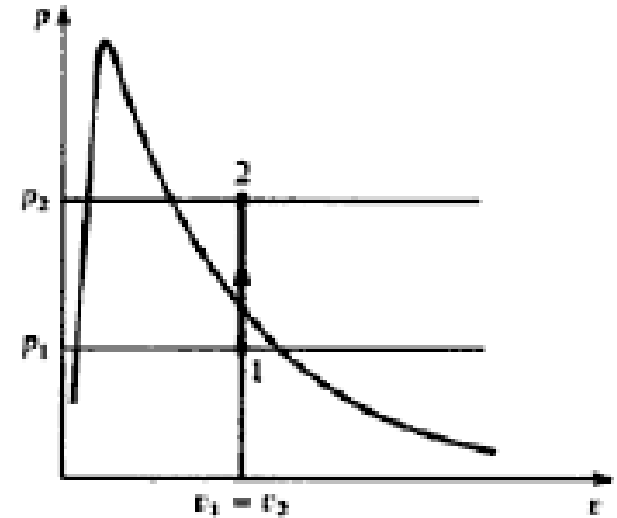> *In Fig. 3.1(b) a constant volume process is shown on a p-v diagram for a perfect gas.*
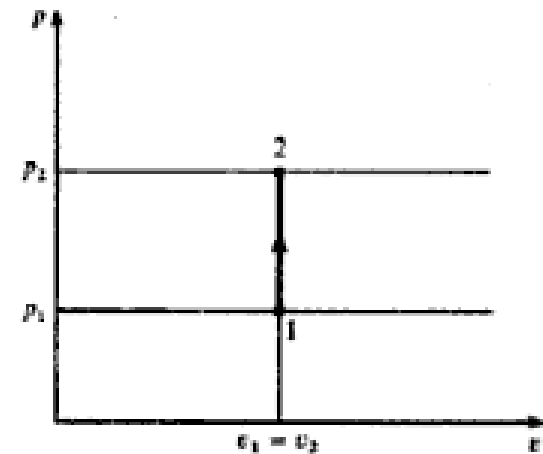
Fig. 3.1(a)

Fig. 3.1(b)

Reversible and Irreversible Processes

Constant Pressure Process:

➢ It can be seen from Figs 3.1(a) and 3.1(b) that when the boundary of the system is inflexible as in a constant volume process, then the pressure rises when heat is supplied.

➢ Hence for a constant pressure process the boundary must move against an external resistance as heat is supplied; for instance a fluid in a cylinder behind a piston can be made to undergo a constant pressure process.
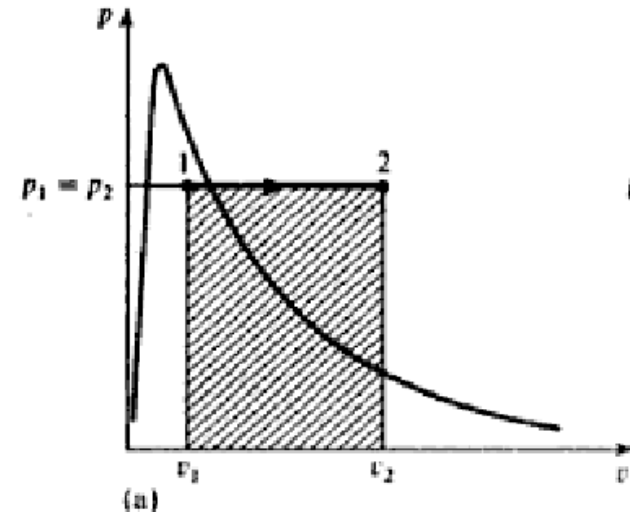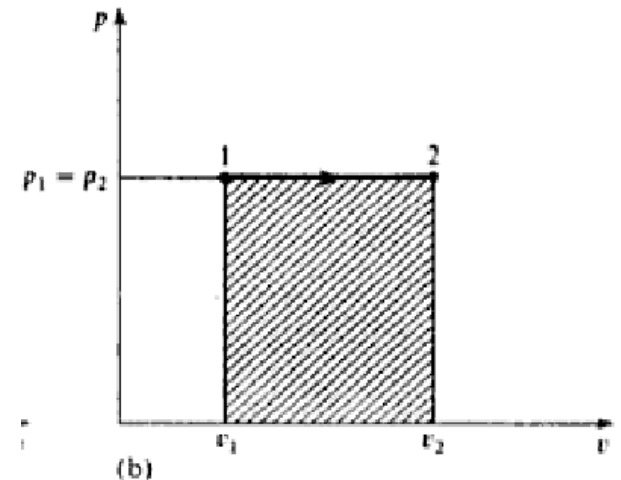
Fig. 3.2(a)

Fig. 3.2(b)

Reversible and Irreversible Processes

Constant Pressure Process:

> Since the piston is pushed through a certain distance by the force exerted by the fluid, then work is done by the fluid on its surroundings. From equation for unit mass for any reversible process

$$W = -\int_{v_1}^{v_2} p\,dv$$

Therefore, since p is constant,

$$W = -p\int_{v_1}^{v_2} dv = -p(v_2 - v_1)$$

From the non-flow energy equation,
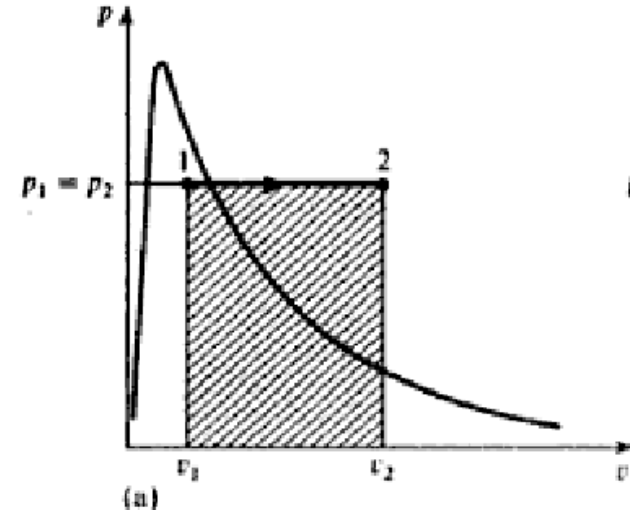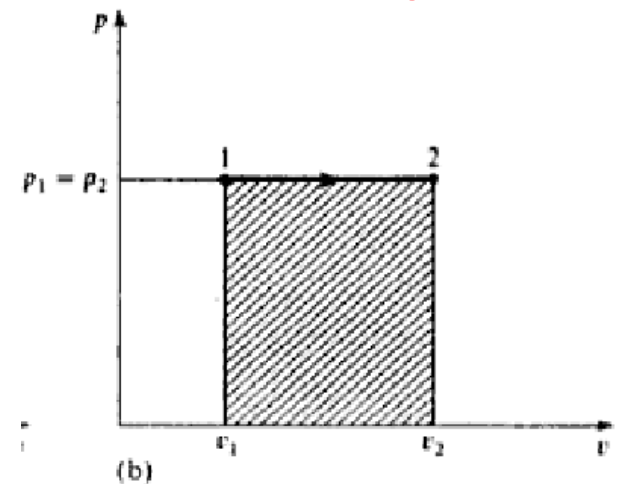
$$Q + W = u_2 - u_1$$

Fig. 3.2(a)

Fig. 3.2(b)

6

Reversible and Irreversible Processes

Constant Pressure Process:

➤ Hence for a reversible constant pressure process

$$Q = (u_2 - u_1) + p(v_2 - v_1)$$

$$Q = (u_2 + pv_2) - (u_1 + pv_1)$$

➤ Now from equation of enthalpy, $h = u + pv$, *hence.*

$$Q = h_2 - h_1 \rightarrow (3)$$

or for mass, m, of a fluid.

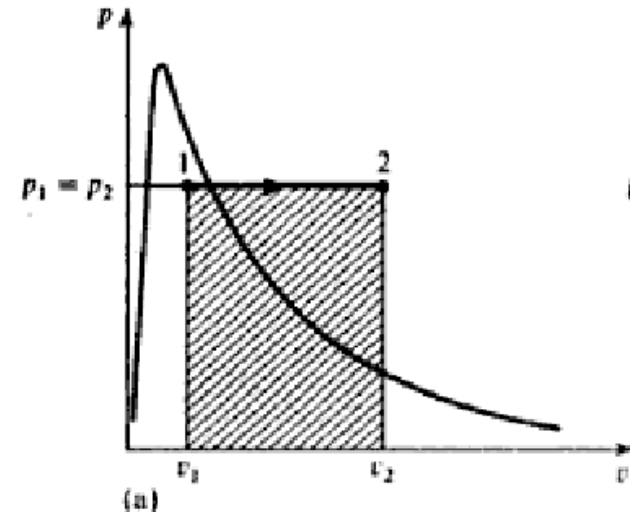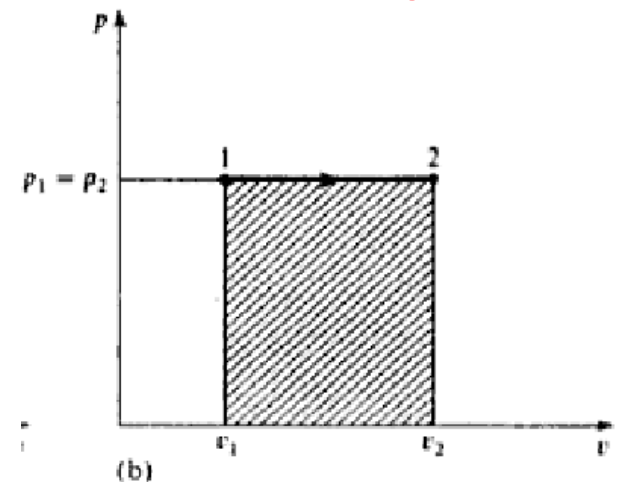$$Q = H_2 - H_1 \rightarrow (4)$$

Fig. 3.2(a)

Fig. 3.2(b)

Reversible and Irreversible Processes

Constant Pressure Process:

A constant pressure process for a vapor is shown on a *p-v diagram in Fig. 2(a). The initial and final states have been chosen to be in the wet region and the superheat region respectively. In Fig. 2(b) a constant pressure process for a perfect gas is shown on a p-v diagram. For a perfect gas we have from* equation

$$Q = mc_P(T_2 - T_1)$$

Note that in Figs 2(a) and 2(b) the shaded areas represent the work done *by the fluid, $p(v_2 - v_1)$.*
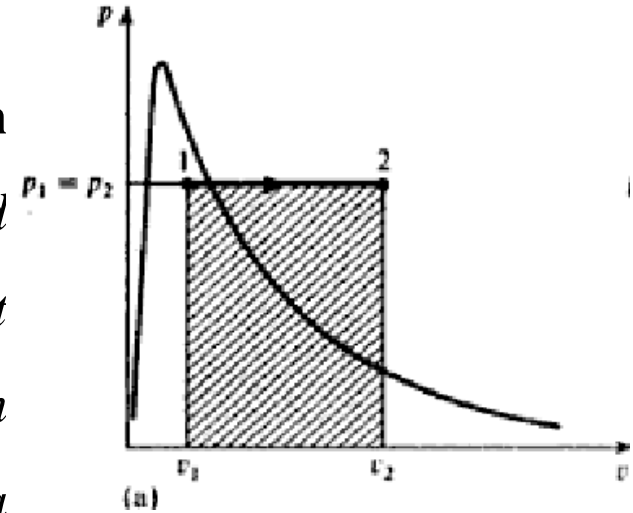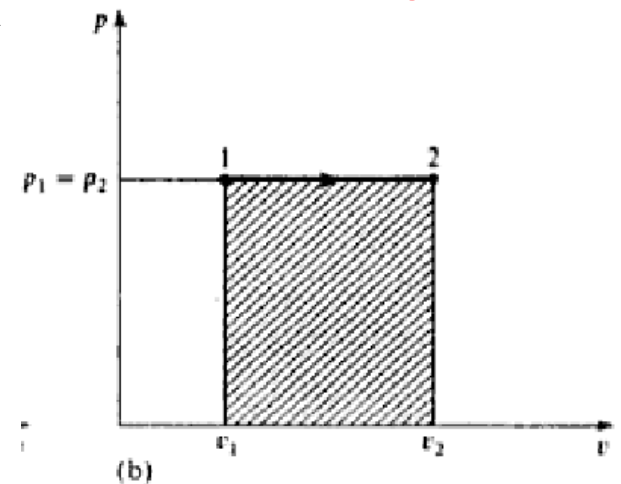

Fig. 3.2(a)

Fig. 3.2(b)

Reversible and Irreversible Processes

Constant Pressure Process:

Example 3.1: A mass of 0.05 kg of a fluid is heated at a constant pressure of 2 bar until the volume occupied is 0.0658 m^3.Calculate the heat supplied and the work done:(i) when the fluid is steam, initially dry saturated; (ii) when the fluid is air, initially at 130 ºC.
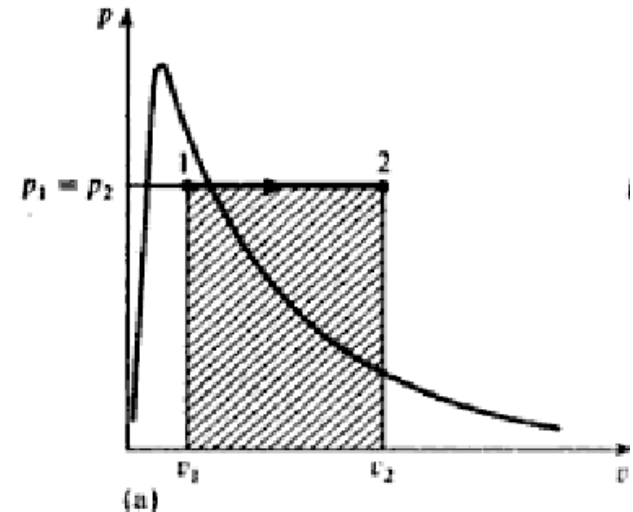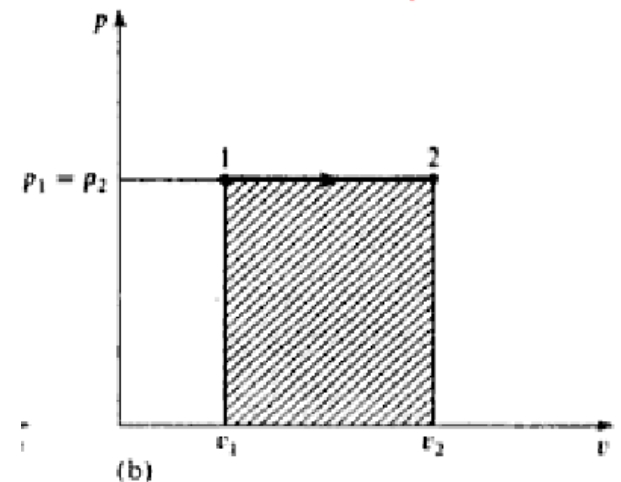

Fig. 3.2(a)

Fig. 3.2(b)

Reversible and Irreversible Processes

Constant Temperature Process:

➢ A process at constant temperature is called an isothermal process.

➢ When a fluid in a cylinder behind a piston expands from a high pressure to a low pressure there is a tendency for the temperature to fall.

➢ In an isothermal expansion heat must be added continuously in order to keep the temperature at the initial value.
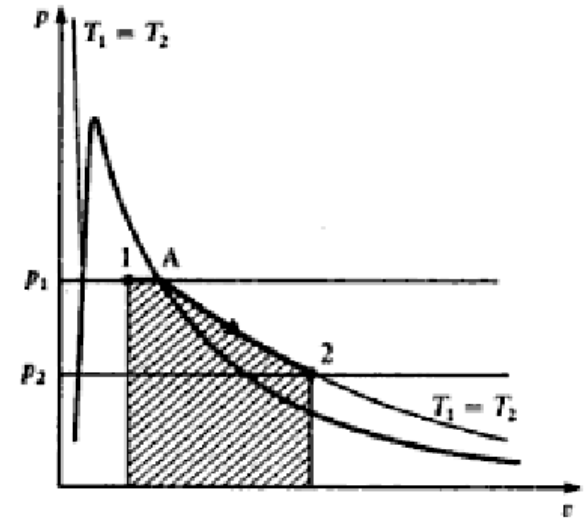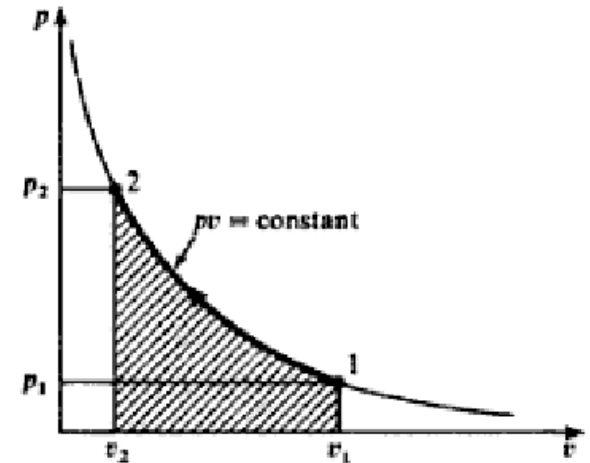
Fig. 3.5)

Fig. 3.7

Reversible and Irreversible Processes

Constant Temperature Process:

➤ Similarly in an isothermal compression heat must be removed from the fluid continuously during the process.

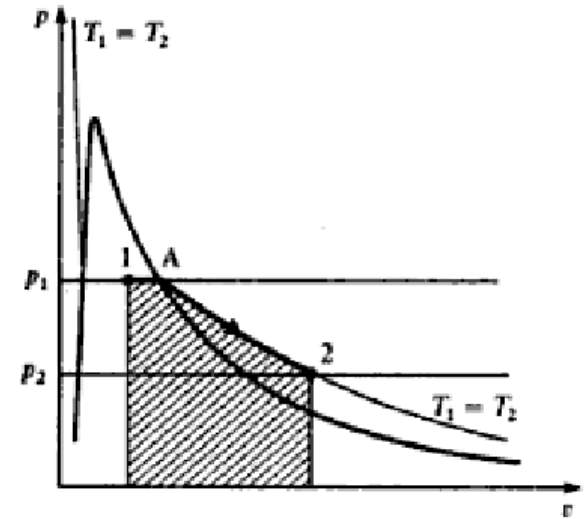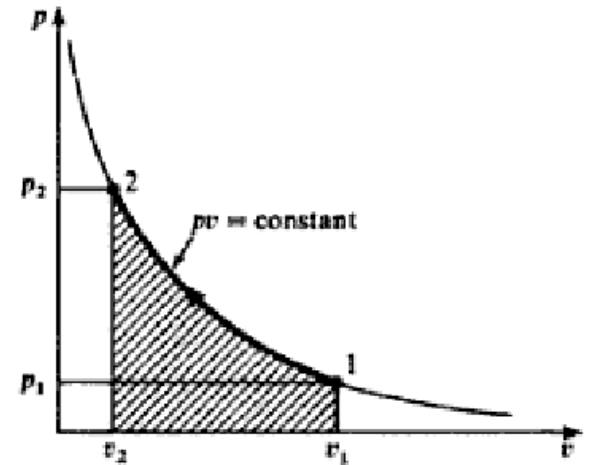Fig. 3.5

Fig. 3.7

Reversible and Irreversible Processes

Constant Temperature Process for Vapors:

➤ An isothermal process for a vapor is shown on a *p-v diagram in Fig. 3.5.*

➤ The initial and final states have been chosen in the wet region and superheat region respectively.

Fig. 3.5

➤ From state 1 to state A the pressure remains at p_1, since in the wet region the pressure and temperature are the corresponding saturation values.

➤ It can be seen therefore that an isothermal process for wet steam is also at constant pressure and equations for constant pressure process can be used (e.g. heat supplied from state 1 to state A per kilogram of steam $= h_A - h_1$).
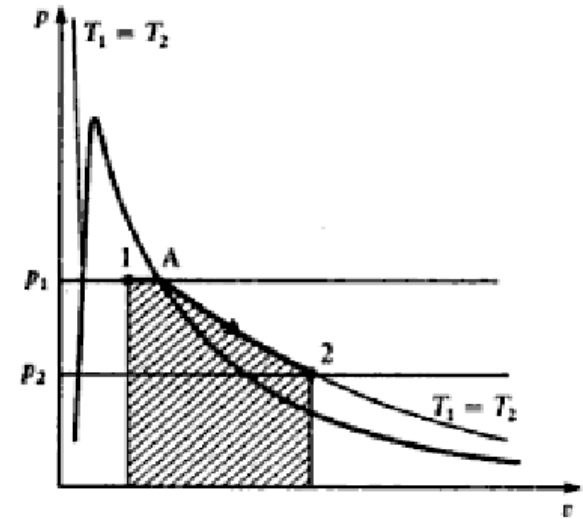
Reversible and Irreversible Processes

Constant Temperature Process for Vapors:

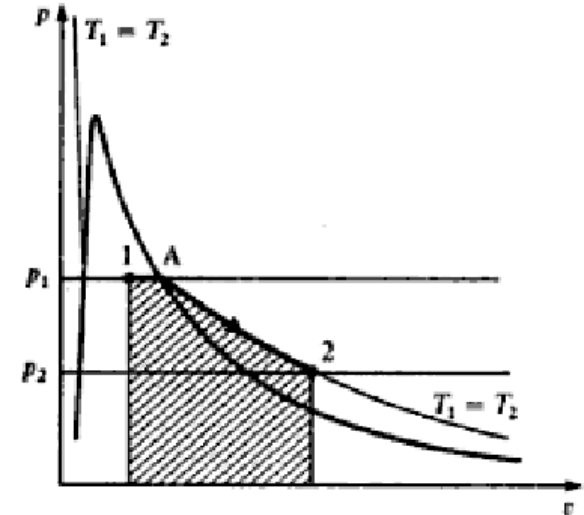➢ In the superheat region the pressure falls to p_2 as shown in Fig. 3.5, and the procedure is not so simple.

<p align="center">Fig. 3.5</p>

➢ When states 1 and 2 are fixed then the internal energies u_1 and u_2 may be obtained from tables.

➢ When the heat flow is calculated the work done can then be obtained using the non-flow energy equation, for unit mass

$$Q + W = u_2 - u_1 \rightarrow (1)$$

Reversible and Irreversible Processes

Constant Temperature Process for Perfect Gas:

➤ An isothermal process for a perfect gas is more easily dealt with than an isothermal process for a vapor, since there are definite laws for a perfect gas relating p, *v*, and *T, and the internal energy u. We have, from equation,*

Fig. 3.7

$$Q + W = u_2 - u_1 \rightarrow (1)$$

➤ When the temperature is constant as in an isothermal process then

$$pv = RT \Rightarrow pv = cont \Rightarrow p_1 v_1 = p_2 v_2 \Rightarrow \frac{v_1}{v_2} = \frac{p_2}{p_1}$$

➤ Since we know that the work done during the process;

$$W = -\int_1^2 pdv = -\int_1^2 \frac{c}{v} dv = -cln\,[v]_1^2 = -cln[lnv_2 - lnv_1] = -cln\frac{v_2}{v_1} = cln\frac{v_1}{v_2} \rightarrow (2)$$
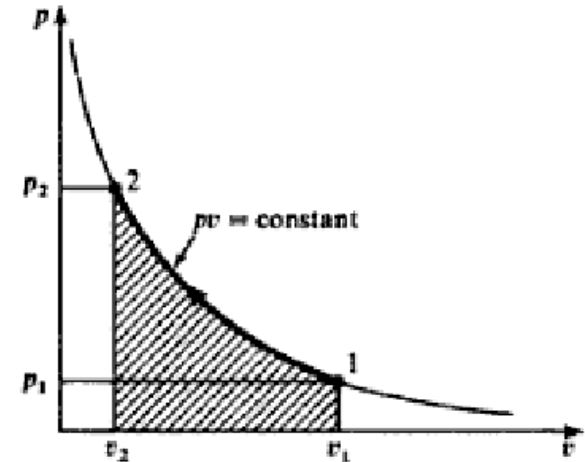
Reversible and Irreversible Processes

Constant Temperature Process for Perfect Gas:

➢ For unit mass of a gas for state point (1) and state point (2) equation (2) can be written as;

$$W = p_1 v_1 \ln\frac{v_1}{v_2} = p_1 v_1 \ln\frac{p_2}{p_1} = RT\ln\frac{p_2}{p_1} \longrightarrow (3)$$

$$W = p_2 v_2 \ln\frac{v_1}{v_2} = p_2 v_2 \ln\frac{p_2}{p_1} = RT\ln\frac{p_2}{p_1} \longrightarrow (4)$$

Fig. 3.7

➢ Similarly for mass "m" of a perfect gas for state point (1) and state point (2) equation (2) can be written as;

$$W = P_1 V_1 \ln\frac{v_1}{v_2} = P_1 V_1 \ln\frac{p_2}{p_1} = mRT\ln\frac{p_2}{p_1} \longrightarrow (5)$$

$$W = P_2 V_2 \ln\frac{v_1}{v_2} = P_2 V_2 \ln\frac{p_2}{p_1} = MRT\ln\frac{p_2}{p_1} \longrightarrow (6)$$
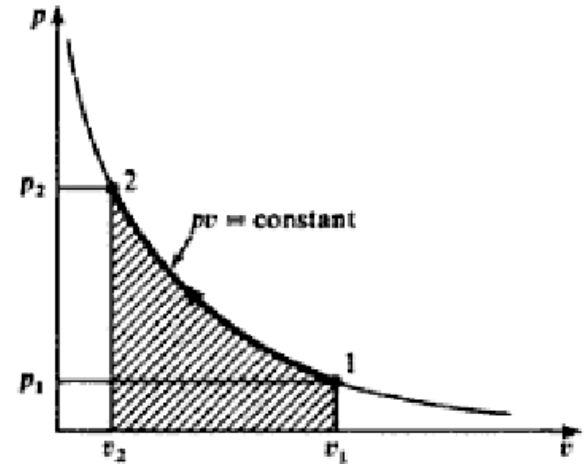
Reversible and Irreversible Processes

<u>Constant Temperature Process for Perfect Gas:</u>

➢ For a perfect gas from Joule's law we have;

$$U_2 - U_1 = mc_v(T_2 - T_1) = mc_v(T_1 - T_1) = 0 \longrightarrow (7)$$

$$u_2 - u_1 = c_v(T_2 - T_1) = c_v(T_1 - T_1) = 0 \longrightarrow (8)$$

➢ By putting all values in equation (1), we have;

$$Q + W = u_2 \text{-} u_1 = 0 \longrightarrow (9)$$

➢ Hence, for a perfect gas in an isothermal process the heat flow plus work input is zero.
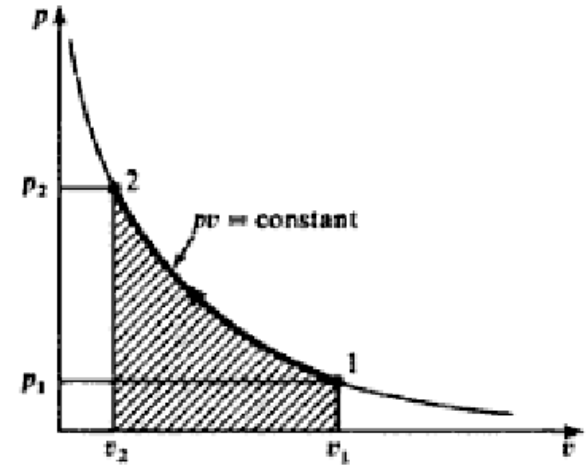

Fig. 3.7

Reversible and Irreversible Processes

Constant Temperature Process for Perfect Gas:

➤ For a perfect gas from Joule's law we have;

$$U_2 - U_1 = mc_v(T_2 - T_1) = mc_v(T_1 - T_1) = 0 \longrightarrow (7)$$

$$u_2 - u_1 = c_v(T_2 - T_1) = c_v(T_1 - T_1) = 0 \longrightarrow (8)$$

➤ By putting all values in equation (1), we have;

$$Q + W = u_2 - u_1 = 0 \longrightarrow (9)$$

➤ Hence, for a perfect gas in an isothermal process the heat flow plus work input is zero.
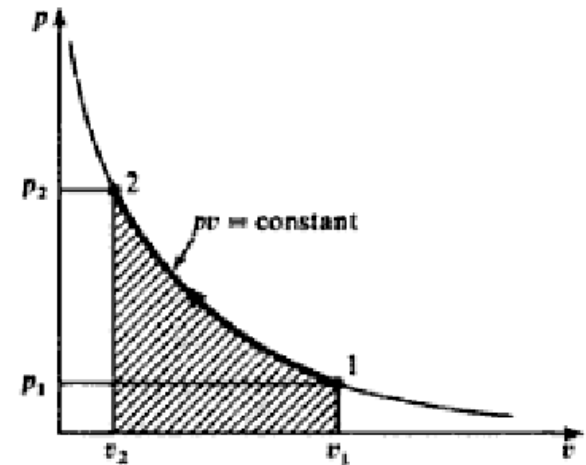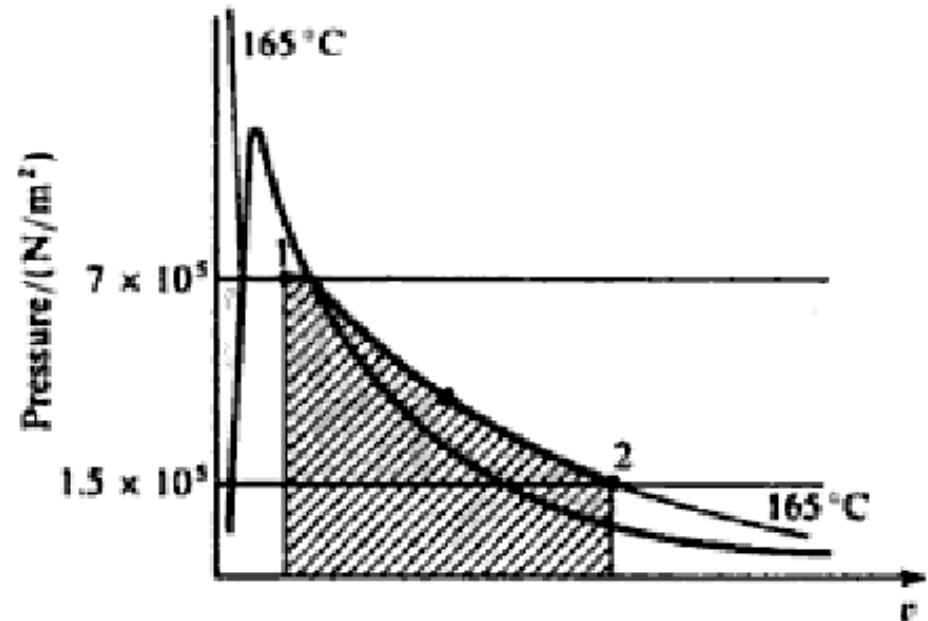

Fig. 3.7

Example 3.2: Steam at 7 bar and dryness fraction 0.9 expands in a cylinder behind a piston isothermally and reversibly to a pressure of 1.5 bar. Calculate the change Of internal energy and the change of enthalpy per kg of steam. The heat supplied during the process is found to be 547kJ/kg. Calculate the work done per kilogram of steam.

Example 3.3: 1 kg of nitrogen (molar mass 28 kg/kmol) is compressed reversibly and isothermally from 1.01 bar, 20°C to 4.2 bar. Calculate the work done and the heat flow during the process. Assume nitrogen to be a perfect gas.
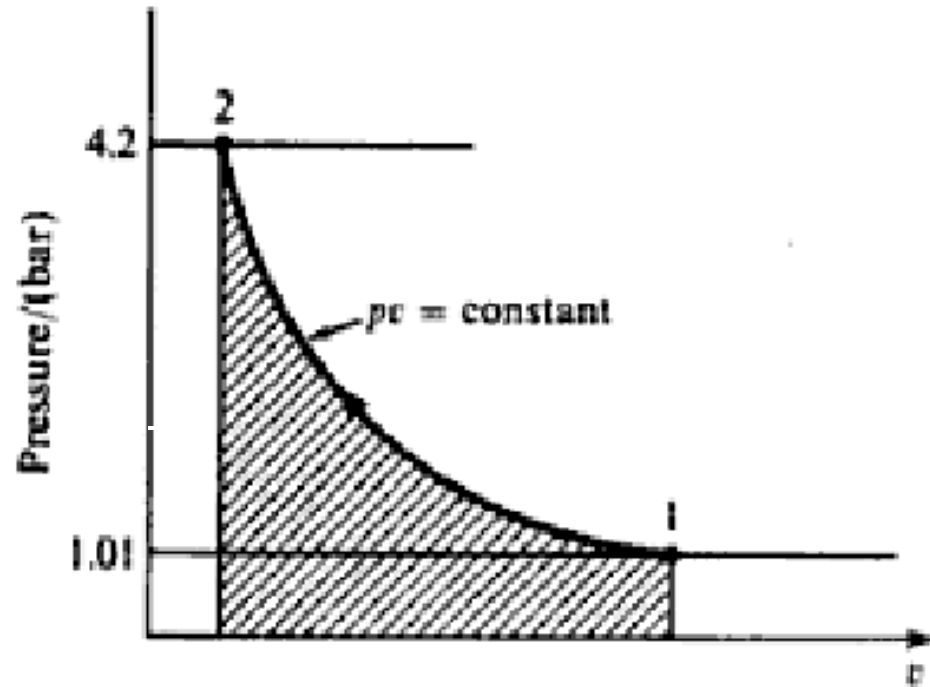
Reversible and Irreversible Processes

Exercise Problems: 3.1, 3.2, 3.3, 3.4, 3.5, 3.6, 3.7