Thermodynamics

Professor Anand T N C
Department of Mechanical Engineering
Indian Institute of Technology, Madras

Lecture 75

Tutorial Problem (1 number)

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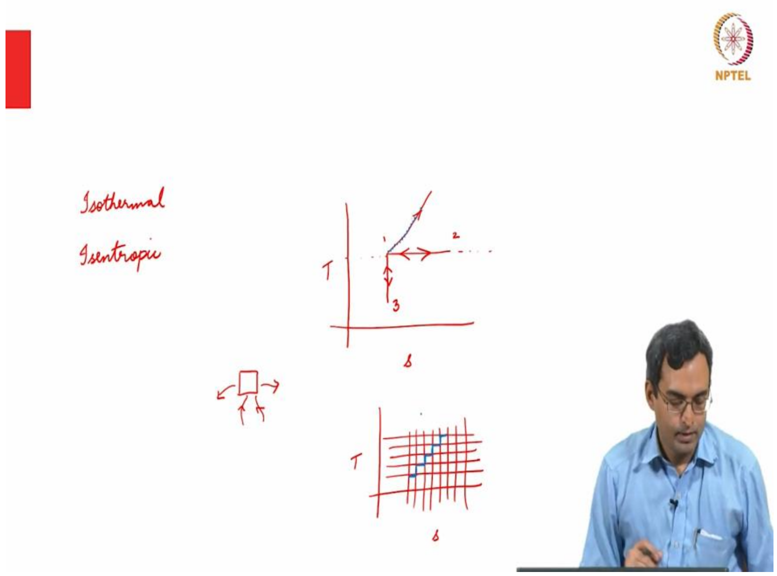

Figure 1.

We know that an isothermal heat addition is a reversible process as the temperature difference across which the heat is being transferred is very small (assuming other sources of irreversibilities are absent). Isothermal process is represented by a line parallel to the S axis on a T-S diagram as shown in Fig. 1 (process 1-2 and process 2-1). Similarly, an isentropic process (reversible and adiabatic) is represented by a line parallel to the T axis on a T-S diagram as shown in Fig. 1 (process 1-3 and process 3-1). We have already discussed the sources of irreversibilities such as friction, a finite temperature difference, unrestrained expansion, etc.

How do we achieve and represent a reversible constant pressure heat addition process on a T-S diagram?

A curve for a constant pressure process which starts at state 1 is shown in Fig. 1. It is not parallel to either T axis or S axis. One way to achieve this process is to have a device/temperature reservoir outside whose temperature is changing with the system's temperature such that the temperature difference is extremely small leading to isothermal heat transfer, which is also reversible.

To represent this process on a T-S diagram, draw a large number of isotherms and isentropes and connect them in a fashion shown by a blue zigzag line as shown on a T-S diagram in Fig. 1. During the isothermal part of the process, we have reversible heat addition. During the isentropic part of the process, we do not have any heat addition, but the process reversible. Hence, combining such isotherms and isentropes, we can obtain a reversible constant pressure heat addition process approximately. The closer the isotherms and isentropes to each other, the better is the approximation. In a similar way, we can draw a reversible constant volume process. We can draw isotherms on a p-V diagram using the similar method.

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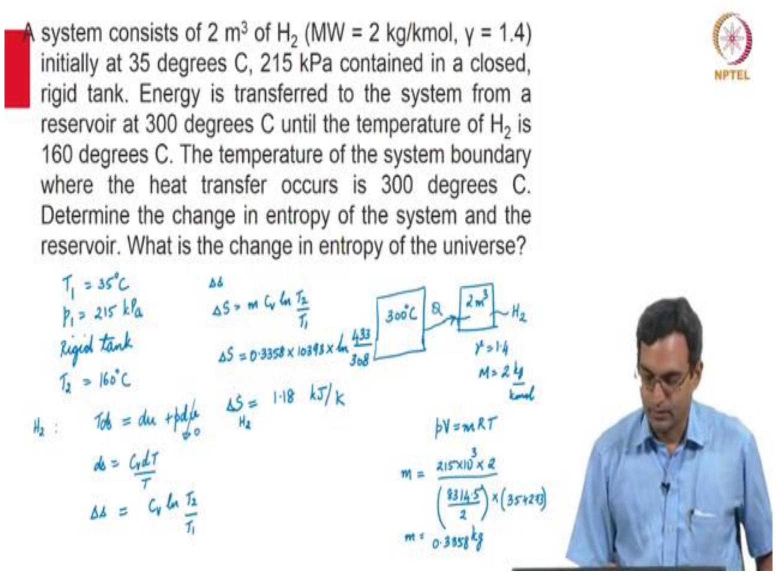
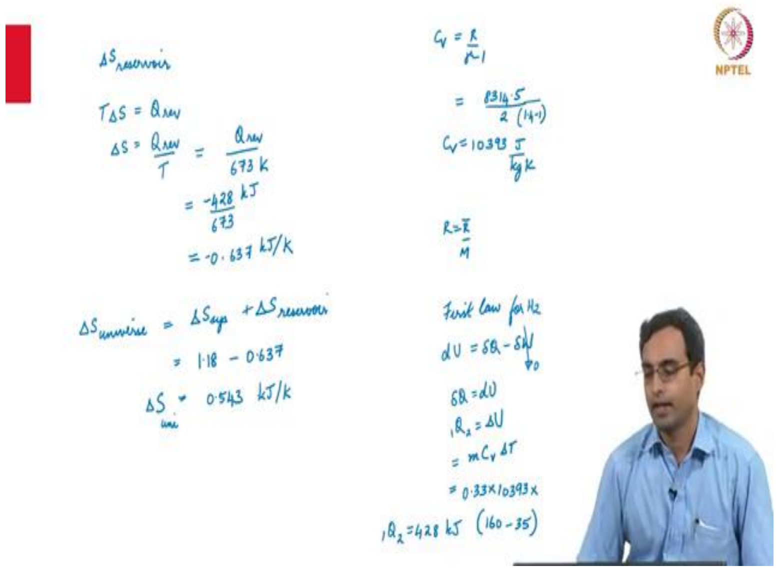


Figure 1.



Solution of the problem in Fig. 1:

For hydrogen,

$T_1 = 35\ ℃ = 308\ K, p_1 = 215\ kPa, T_2 = 160\ ℃ = 433\ K, V = 2\ m^3$

H_2 is contained in a closed rigid tank. Hence, there is no volume change during the process.

A schematic of the reservoir at 300 ℃ and the tank of H_2 is shown in Fig. 1.

For hydrogen, $Tds = du + pdv \ \rightarrow Tds = du = C_v dT$ (as dv=0)

Hence, $ds = C_v \frac{dT}{T}$. Integrating, $\Delta s_{H_2} = C_v \ln\left(\frac{T_2}{T_1}\right) \quad \rightarrow \quad \Delta S_{H_2} = mC_v \ln\left(\frac{T_2}{T_1}\right)$….(1)

We need to calculate C_v and the mass m for hydrogen.

$C_v = \frac{R}{\gamma - 1} = \frac{8314.5/2}{1.4-1} = 10393\ \frac{J}{kg \cdot K}$ ($M_{H_2} = 2\ \frac{kg}{kmol}$ and γ for a diatomic gas like hydrogen is 1.4)

Assuming hydrogen to be an ideal gas, $m_{H_2} = \frac{p_1 V}{RT_1} = \frac{215 \times 10^3 \times 2}{(8314.5/2) \times 308} = 0.3358\ kg.$

Equation (1) implies $\Delta S_{H_2} = 0.3358 \times 10393 \times \ln\left(\frac{433}{308}\right) = 1.18 \frac{kJ}{K}$.

For the reservoir, the heat transfer is reversible as it happens isothermally. The boundary of the system through which the heat is entering is also at 300 °C, i.e., at the reservoir temperature.

For a reversible process, $\Delta S_{reservoir} = \frac{Q_{rev}}{T}$. T = 400 °C $= 673\ K$. We need to calculate Q_{rev}.

The heat gained by hydrogen equals the heat lost by the reservoir.

Writing the first law for the process undergone by hydrogen, $dU = \delta Q - \delta W \quad \rightarrow \quad dU = \delta Q$ (There is no change in kinetic and potential energy of the system, hence dE=dU. δW is 0 as it is a constant volume process.)

Now, $\delta Q = dU = mC_v dT$. Integrating, $Q = mC_v \Delta T = 0.3358 \times 10393 \times (433 - 308) = 128\ kJ$.

This heat transfer is negative for the reservoir as heat is leaving it.

Hence, $\Delta S_{reservoir} = -\frac{428}{673} = -0.637\frac{kJ}{K}$.

Now, $\Delta S_{universe} = \Delta S_{reservoir} + \Delta S_{H_2} = 0.543\frac{kJ}{K}$

The process for the reservoir is reversible. However, the process for hydrogen is irreversible. Hence, $\Delta S_{universe}$ is positive. The entropy of the universe (isolated system) increases because of the irreversible process.