

ENTROPY

Entropy, S , is a property of a system, such that its increase $(S_2 - S_1)$ as the system changes from state 1 to state 2.

$$S = S_2 - S_1 = \int_1^2 \frac{dQ_R}{T}$$

$T \rightarrow$ absolute temp. of steam

* S is a property, value of integral is independent of the path of the change of state and depends only on the end-states 1 and 2.

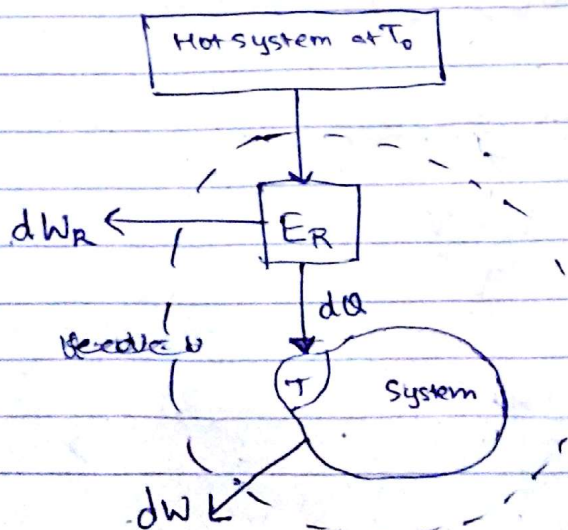
Proof: Entropy is a property: CLAUSIUS INEQUALITY

Statement: When any system undergoes a cyclic process, the integral around the cycle $\oint \frac{dQ}{T}$ is less than or equal to zero.

$$\oint \frac{dQ}{T} \leq 0$$

$dQ \rightarrow$ infinitesimal heat transfer

$T \rightarrow$ absolute temp. of the part of the system to which heat transfer dQ occurs.



\rightarrow System does work dW as dQ enters it simultaneously.

\rightarrow Surrounding is replaced with system at const. temp. at T_0

NOTE:

Second law of Thermodynamics

→ It is impossible to cause an engine to operate (thermodynamic) cycle in which the only interactions are positive work done on the surroundings and heat transfer from a system which remains at const. temperature.

$$\oint dW \leq 0$$

Single
★ Constant temp.
System ($Q_2 = 0$)

Applying First law to the system as it completes its cyclic process ($\Delta U = 0$)

$$\oint (dQ - dW) = 0 \quad \text{--- (1)}$$

Applying second law to the combined system within the dotted boundary

$$\oint (dW + dW_R) \leq 0 \quad \text{--- (2)}$$

Involving absolute temp. scale

$$\frac{dW_R}{dQ} = \frac{T_0 - T}{T}$$

$$\frac{dW_R}{T_0 - T} = \frac{dQ}{T} \quad \text{--- (3)}$$

From

~~ΔQ~~ (1) and (2) we get

$$\oint dQ + dW_R \leq 0$$

$$\oint \left\{ dQ + \frac{(T_0 - T)}{T} dQ \right\} \leq 0$$

$$T_0 \oint \frac{dQ}{T} \leq 0$$

$$\boxed{\oint \frac{dQ}{T} \leq 0}$$

↓
Clausius Inequality.

DISCUSSION OF ENTROPY

- (1) Entropy is a property
- (2) Entropy is an extensive property.

$$\boxed{S = S_f + x(S_g - S_f)}$$

↑
specific
entropy

[The entropy S of
wet steam of dryness
 x]

Intensive property
(independent of mass)

ef. density, M.P, B.P,
color, taste.

* ISENTROPIC PROCESS : $dQ_R = 0$
 $\Delta S = 0$

A process in which the entropy
remains constant is known as
isentropic process.

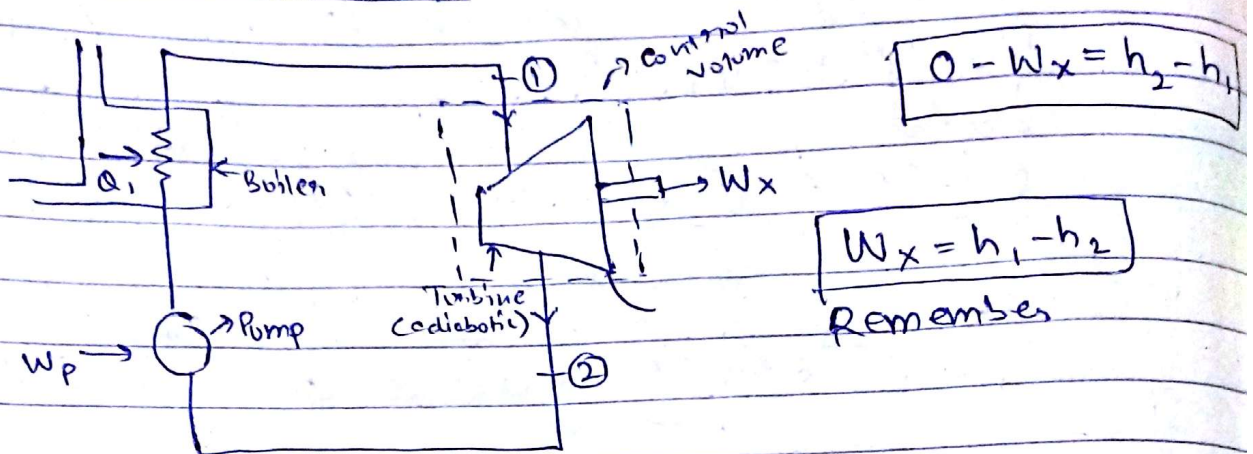
Extensive property
(dependent of mass)

ef. mass, volume,
length.

— All REVERSIBLE ADIABATIC
PROCESS are isentropic

Case 1:

A turbine example



→ Whenever in question, maximum output i.e. max^m heat transfer, max^m work. Consider the system as reversible.

→ During adiabatic reversible process (isentropic)

$$S_1 = S_2 \quad \star \star \star$$

(Performance of actual adiabatic machine is compared with reversible one)

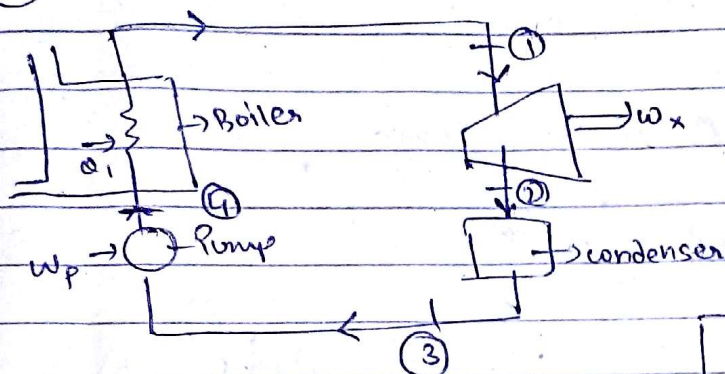
⇒ Isentropic efficiency: (η_{isen}) of an adiabatic work producing machine is the ratio of the actual work output to the work output of a reversible adiabatic. As shown in case 1 taking in liquid at some initial state and exhausting it at the same final press.

$$\eta_{isen} \equiv \frac{W_x}{W_{x,r}} \quad \star \star \quad \text{①}$$

Similar measures of performance are used for adiabatic machines in which work is done on the fluid. eg. rotary compressors.

$$\eta_{isen} \equiv \frac{W_{x,R}}{W_x}$$

RANKINE CYCLE EFFICIENCY:



$$\eta_{Rankine} = \frac{W_{x,R}}{h_1 - h_{f2}}$$

where

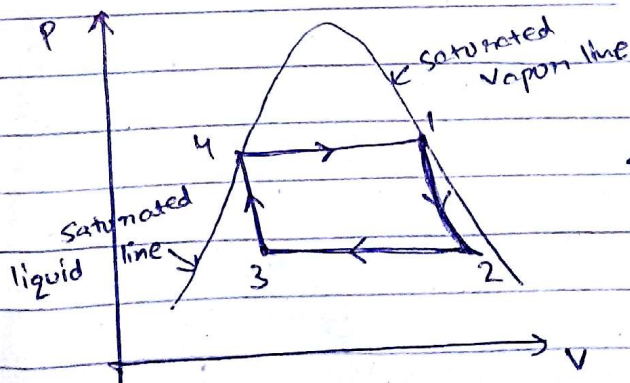
h_1 = enthalpy of steam entering machine

h_{f2} = enthalpy of saturated water at the pressure of exhaust steam

[i.e. press. at 2 = Press. at 3]

in above case

$$h_{f2} = h_3$$



State 2 and state 3 are at same press.

$$\text{efficiency ratio} = \frac{\eta}{\eta_{Rankine}}$$

where

$$\eta = \frac{W_x}{h_1 - h_{f2}}$$

→ it is identical with η_{isen} bcoz small feed pump work has been neglected. Strictly the feed pump term should be taken into account in η and $\eta_{Rankine}$.

→ Quantitative test for irreversibility in adiabatic system

any
For an irreversible process

i,
$$S_2 - S_1 > \int_1^2 \frac{dq}{T}$$

For adiabatic irreversible process

ii,
$$S_2 - S_1 > 0$$

Entropy increase of a pure substance

$$\boxed{du + pdv = Tds} \rightarrow *$$

$$h = u + pv$$
$$dh = du + pdv + vdp$$

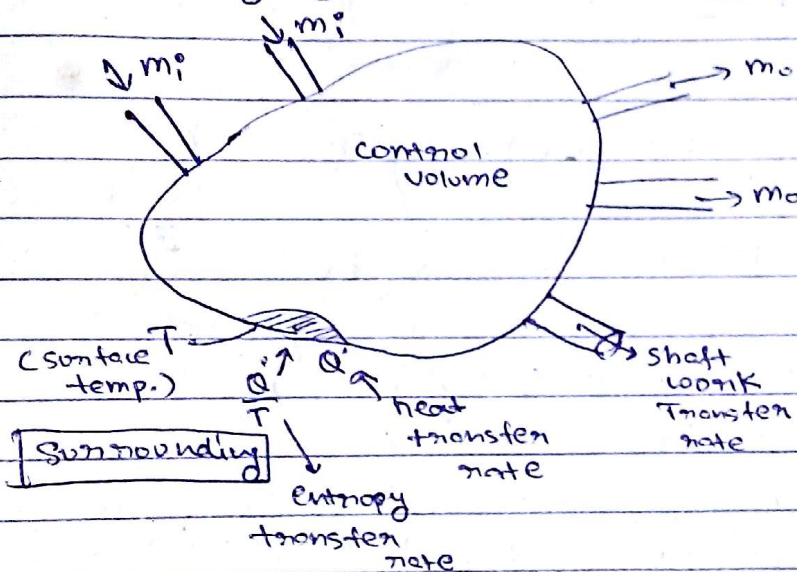
$$\boxed{dh + vdp = Tds} \rightarrow *$$

* Entropy change for the process when two ideal gases mix together in an insulated chamber.

$$\Delta S = -\bar{R} (n_1 \ln x_1 + n_2 \ln x_2)$$

$$n_1 \rightarrow \text{moles}, \quad x_1 = \text{mole fraction} \rightarrow x_2 = \frac{n_2}{n_1 + n_2} \\ = \frac{n_1}{n_1 + n_2}$$

Entropy generation in an open system



eqn. of continuity gives

$$\sum \dot{m}_{in} - \sum \dot{m}_{out} = \frac{\partial M}{\partial \tau}$$

rate of mass accumulation in the CV

At steady state

$$\sum \dot{m}_{in} = \sum \dot{m}_{out}$$

$$\sum \dot{m}_{in} \left(h + \frac{V^2}{2} + gz \right)_{in} - \sum \dot{m}_{out} \left(h + \frac{V^2}{2} + gz \right)_e + \dot{Q} - \dot{W}_{sh} = \frac{\partial E}{\partial \tau}$$

$$\sum \dot{m}_{in} S_{in} - \sum \dot{m}_{out} S_{out} + \frac{\dot{Q}}{T} \leq \frac{\partial S}{\partial \tau}$$

net rate of entropy transfer

rate of increase of entropy of CV

Rate of entropy generation

$$\dot{S}_{gen} = \frac{\partial S}{\partial \tau} - \sum m_{in} S_{in} + \sum m_{out} S_{out} - \left(\frac{\dot{Q}}{T} \right)$$

In steady flow $\frac{\partial S}{\partial \tau} = 0$

$$\dot{S}_{gen} \geq 0 \quad \text{Always}$$

Valid
for
irreversible
also

Entropy transfer from surroundings

Enthalpy-Entropy Chart for Steam. Edward Arnold, London, 1962.
 MOLLIER, R. *Neue Tabellen und Diagramme für Wasserdampf*. Springer, Berlin, 1906.

CHAPTER 13—PROBLEMS

13.1 (a) A fluid system at a temperature of 60°C and a pressure of $90 \times 10^3 \text{ N/m}^2$ undergoes a reversible process during which the temperature of the system remains constant. Given that the heat transfer to the fluid during the process is 120 kJ , evaluate the increase in entropy.

(b) The system in (a) has a mass of 2.31 kg . Evaluate the increase in the specific entropy of the system.

(c) A second fluid system, identical to that in (a), undergoes an irreversible isothermal process from the same initial state to the same final state as in (a). The heat transfer to the fluid in this irreversible process is 80 kJ . Evaluate the increase in the specific entropy of the fluid.

13.2 Using the Steam Tables given in Appendix B, obtain the magnitude and units for each of the following:

(a) Specific entropy of dry-saturated steam at a temperature of 150°C .

(b) Specific entropy of saturated water at a pressure of $7 \times 10^3 \text{ N/m}^2$.

(c) Specific entropy of steam at a pressure of $700 \times 10^3 \text{ N/m}^2$, dryness 0.9 .

(d) Specific entropy of steam at a pressure of $400 \times 10^3 \text{ N/m}^2$ and a temperature of 600°C .

13.3 (a) A system consists of a mixture of 0.1 kg of saturated water and 0.7 kg of saturated steam in equilibrium at $300 \times 10^3 \text{ N/m}^2$. Evaluate the dryness fraction, the temperature and the specific entropy of the mixture.

(b) Steam at a temperature of 250°C has a specific entropy of 6.97 kJ/kg K . Evaluate the pressure, the specific volume and the specific internal energy of the steam.

Entropy is a state func.