Availability

Available energy is the maximum portion of energy which could be converted into useful work by ideal processes which reduces the system to a dead state (state equilibrium with the earth and its atmosphere)

If a system within the surroundings is in equilibrium with the surroundings and itself is in an equilibrium state, then there can be no interaction between the two. This is called the "dead state".

If the system is in some states other than the dead state, it will change spontaneously toward the dead state. The work done by the system in changing to the dead state. The work done by the system in changing to the dead state will never be less than zero i.e. W max $\geq O$, where W max is the maximum useful work that can be produced by the system as it interact with the surroundings in achieving the dead state.

Availability (Exergy): Availability is a measure of the maximum amount of useful work that can be obtained from a system interacting with the surroundings at any state P_1 and T_1 when operating with a reservoir at constant pressure and temperature P_o and T_o.

Note: Anergy and Exergy → Energy

Max Work   Max useful work – Exergy

Unusable work

Q = A.E + U.E

Or W_{max} = A.E = Q – U.E

From η_{max} $(circle\ Efficeincy)= \dfrac{T - T_o}{T} = \dfrac{T_o}{T}$

Reversible heat transfer from a system

From $\eta_{max} = \dfrac{\partial w}{-\partial Q}$

$\partial_w = \eta_{max} - \partial Q$

$= \left(\dfrac{T - T_o}{T}\right) - \partial Q$

$= \left(\dfrac{T_o - T}{T}\right) dQ$

During change in volume (dv) which is resisted by the pressure of the surroundings, P_o

Network = $\partial_w - P_o dV$

∴ *Note* : The network is the sum of all the individual work

i.e. $\quad \partial_{wnet} = \partial w - P_o dV + \partial_Q \left(\dfrac{T_o}{T} - 1 \right)$

$\quad = \partial w - P_o dV + \dfrac{T_o}{T} \partial_Q - \partial_Q$

$\quad = \partial w - P_o dV - \partial Q + \dfrac{T_o \partial Q}{T}$

$\quad = \partial w - \partial Q - P_o dV + T_o \dfrac{\partial Q}{T}$ 1

From the first law of thermodynamics for a closed system undergoing a reversible process,

$\quad \partial Q = du + \partial w$

$\quad - du = \partial w - \partial Q$

Substitute (-du) in equation 1

$\quad \partial w_{net} = du - Podv + Tods \quad \sin ce \; ds = \left(\dfrac{dQ}{T} \right)_{rev}$

$\quad \therefore dw_{net} = -\left(du + P_o dv - T_o ds \right)$

$\quad \therefore W_{max} = -\int_1^o \left(du + P_o dv - T_o ds \right)$ (Max work that can be accomplished by any system at

state 1 to state 0 can be represented by the decrease in this function

$\quad = -\left[\left(U_o - U_1 \right) + P_o \left(V_o - V_1 \right) - T_o \left(S_o - S_1 \right) \right]$

$\quad = -\left[\left(U_o - U_1 + P_o V_o - P_o V_1 - T_o S_o + T_o S_1 \right) \right]$

$\quad = -U_o - U_1 - P_o V_o + P_o V_1 + T_o S_o - T_o S_1$

$\quad = \left(U_1 + P_o V_1 - T_o S_1 \right) - \left(U_o + P_o V_o - T_o S_o \right)$

$W_{max} = A_1 - A_o$

The function A = $\left(U + P_o V - T_o ds \right)$ is known as the non-flow availability function which is a composite property in that it is not only a function of the system but also of its surroundings.

Availability in Steady Flow

$$W_{max} = \left(U_1 + P_1 V_1 + \frac{C_1^2}{2} + Z_1 g \right) - U_o + P_o V_o - T_o \left(S_1 - S_o \right)$$

$$= U_1 + P_1 V_1 - U_o - P_o V_o - T_o S_1 + T_o S_0 \ (\textit{Neglect Kinetic / Potential Energy}$$

$$= \left(U_1 + P_1 V_1 - T_o S_1 \right) - \left(U_o + P_o V_o - T_o S_0 \right)$$

$$= \left(G_1 - G_o \right)$$

The concept of availability may be expressed in terms of another thermodynamics function. The Gibbs function or free energy, G, which is defined as G=H-TS

$$dG = dH - \left(Tds + SdT \right)$$

$$= dH - Tds - SdT$$

Also,

$$H = U + PV$$

$$dH = du + PdV + Vdp$$

$$dG = du + Pdv + Vdp - Tds - SdT$$

Conditions of constant temperature and pressure where the temperature is T_o and the pressure is P_o, yields for the Gibbs function

$$dG = du + Podv - Tods$$

$$dG = G_1 - G_o$$

AVAILABLE ENERGY FOR SYSTEMS WITH HEAT TRANSFER

From $Q_1 = A.E + U.E$

But $W_{max} = A.E$

$$= Q_1 - U.E$$

However, $\partial w_{max} = \partial(A.E)$

$$\partial(A.E) = \partial Q \left(1 - \frac{T_o}{T} \right)$$

$$= \partial Q - \partial Q \frac{T_o}{T}$$

By integrating from state 1 to state 2

$$\int_1^2 d\,(A.E) = \int_1^2 \partial Q - T_o \int_1^2 \frac{dQ}{T}$$

$$(A.E)_{1-2} = \int_1^2 \partial Q - T_o\,(ds)$$

$$Availability\ Energy\,(A.E)_{1-2} = Q_{1-2} - T_o\,(S_2 - S_1)$$

Also,

$$(A.E)_{1-2} = \int_1^2 dQ - To\int_1^2 \frac{\partial Q}{T}$$

$$= \int_1^2 dQ - To\int_1^2 \frac{Mc_p\,dT}{T}$$

$$= \int_1^2 dQ - TMc_p\int \frac{dT}{T}$$

$$= \int_1^2 dQ - ToMc_p\ \ln \frac{T_2}{T_1}$$

$$(A.E)_{1-2} = Q_{1-2} - To\,Mc_p\ \ln \frac{T_2}{T_1}$$

$$\therefore (U.A)_{1-2} = T_o\,(S_2 - S_1) = T_o\,Mc_p\ \ln\left(\frac{T_2}{T_1}\right)$$

Again from gas equation

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

$$\frac{V_2}{V_1} = \frac{P_1}{P_2}\ x\ \frac{T_2}{T_1}$$

Putting the value of $\dfrac{V_2}{V_1}$ in equation 1

$$(S_2 - S_1) = Cv\log_e \frac{T_2}{T_1} + R\log_e \frac{P_1}{P_2}\,x\,\frac{T_2}{T_1}$$

$$= Cv\log_e \frac{T_2}{T_1} + R\log_e \frac{P_2}{P_1} + R\ \log_e \frac{T_2}{T_1}$$

$$= (C_v + R)\log_e \frac{T_2}{T_1} - R\ \log_e \frac{P_2}{P_1}$$

$$= Cp\log_e \frac{T_2}{T_1} - R\log_e \frac{P_2}{P_1}$$

Examples 4.1

If 300KJ of heat are reversibly added to 0.2kg of air at constant pressure and initial temperature is 300°C, find the available and unavailable energies of the heat added. The temperature of the surroundings is 30°C.

SOLUTION

Given: Q=300KJ, M_{ar} = 0.2kg, T_1 = 300°C = 300 + 273 = 573K

To = 300°C = 30 + 273 = 303K Cpar = 2005KJ kgk

Required: A.E = ?, U.E.=? T_2 =?

To determine T_2

$Q = AH = Mcp (T_2-T_1)$

$T_2 = Q + T_1 = 300 + 573 = 2066k$

$$(A.E)_{1\text{-}2} = Q_{1\text{-}2} - To\ mcp\ In\left(\frac{T_2}{T_1}\right)$$

$$= 300 - (303)(0.2)(1005)\ In\left(\frac{2066}{573}\right)$$

$$= 300 - 78.111 = 221.89\ J$$

$$(U.E)_{1-2} = Q_{1-2} - (A.E)_{1-2} = 78.11KJ$$

EXAMPLE 4.2

It is required to remove 500KJ of heat from or construct temperature reservoir of 835K. The heat is received by a system at constant temperature of 720k. The temperature of the surroundings, the lowest available temperature is 280k. Find the net loss of available energy as a result of the irreversible heat transfer.

SOLUTION

Given: Q = 500KJ, T_o = 280K, $T_{1\text{-}2}$ = 835K, $T_{3\text{-}4}$ = 720K

Required: (A.E)$_{net}$ = ?

A T-S diagram illustrating the processes

The total heat is the same in both the heat reservoir or system

$(A.E)_{1\text{-}2} = Q_{1\text{-}2} - T_o (S_2\text{-}S_1)$

$$= Q_{1\text{-}2} - T_o\ \frac{\partial Q}{T_{1-2}}$$

$$= -500 - 280\left(\frac{-500}{835}\right)$$

$$= -332.34\,KJ$$

$$\left(A.E\right)_{3-4} = Q_{3-4} - T_o\left(S_4 - S_3\right)$$

$$\left(A..I\right)_{3-4} = Q_{3-4} - \frac{T_o dQ}{T_{3-4}}$$

$$= +500 - 280\left(\frac{+500}{720}\right)$$

$$= +305.55KJ$$

$$\left(A.E_{net}\right) = \Sigma\left(A.E\right)$$

$$= \left(+305.55 - 332.34\right)KJ$$

$$= -26.78KJ$$

There is a net loss of available energy the heat transfer process, and this is equal to the net gain in unavailable energy

$$\left(U.E\right)_{1-2} = To\left(S_2 - S_1\right) = To\,dQ$$

$$= -280\left(\frac{-500}{835}\right) = 107.66KJ$$

$$\left(U.E\right)_{3-4} = To\left(S_4 - S_3\right) = To\frac{dQ}{To}$$

$$= +280\left(\frac{+500}{720}\right) = +194.44KJ$$

$$\left(U.E\right)net = \Sigma_1\left(U.E\right)$$

$$= \left(194.44 = 167.66\right)KJ$$

$$= +26.78KJ$$

The use of a T-S diagram is very useful in visualizing heat, available energy, and unavailable energy.

It is primetimes easier to find the net gain of unavailable energy $(U.E)_{net} = T_o\,AS_{net}$) than the net less of available energy.

$$(A.E)_{5-4} = Q_{3-4} - To \; dQ$$

$$= +500 - 280 \left(\frac{+500}{720} \right)$$

$$= +305.55 KJ$$

$$(A.E)_{net} = \Sigma_i \, (A.E)$$

$$= (-305.55 - 332.34)KJ$$

$$= -26.78KJ$$

There is a net loss of available energy in the heat transfer process, and this is equal to the net gain in unavailable energy.

$$(U.E)_{1-2} = To \, (S_2 - S_1) = To \; \frac{dQ}{T_{1-2}}$$

$$= +280 \left(\frac{-500}{835} \right) = -107.66KJ$$

$$(U.E)_{3-4} = To \, (S_4 - S_3) = To \; \frac{dQ}{T_{1-2}}$$

$$= +280 \left(\frac{-500}{720} \right) = +194.44KJ$$

$$(U.E)_{net} = \Sigma i (U.E)$$

$$= (194.44 - 167.66)KJ$$

$$= +26.78KJ$$

The use of a T-S diagram is very useful in visualizing heat, available energy, and unavailable energy.

It is sometimes easier to find the net gain of unavailable energy $(U.E)_{net} = To \, \Delta S_{net})$ than the less of available energy.

PRACTICE QUESTIONS

1. Determine the available energy of finance gas SP 046KJ/kg. K when is seized from 1260K. i.e. 480k at constant pressure. The surroundings is at 295k

2. A carnot engine receives heat from a constant temperature reservoir. The engine has a maximum temperature of 820k. For each 1100KJ of heat transferred, compute the net change of entropy when the high-temperature reservoir is at the following temperatures: (a) 1700K; (b) 1425K (c) 875K.

3. At constant pressure, 138Pa, 5kg air is cooled from 500K to 300K. The temperature of the surroundings is 277k. Determine the available portion of the heal removed and the entropy increase of the universe

4. Steam is contained in constant pressure closed system at 200kPa and 202°C and is allowed to reach thermal equilibrium with the surroundings which is at 26°C. Find the loss of available energy per kilogram of steam