

EXERGY ANALYSIS IN THERMAL SYSTEM

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Energy plays a vital role in a country's economic development and it is expected to be more significant in the coming years due to the increasing demand. A multi-dimensional approach is therefore required keeping in view the various economic options available through effective demand management. Thus energy conservation and efficient use of energy becomes a major supply option.

Technical experts always use the phrase "Energy conservation". Is there any meaning in this? According to the 1st law of thermodynamics energy is conserved everywhere. It can be converted to different forms, but it cannot be destroyed. The total energy of the earth is changing very little. If solar radiation and outgoing heat flux are balanced it is not changing at all. So it is not needed to conserve energy.

Let's get a small example. Suppose a large enclosure, say a large room, consisting of a small container of fuel surrounded by air in abundance. The fuel burns. After the combustion, there is a slightly warmer mixture of combustion products and air. Assume the process is adiabatic. Then the total quantity of energy in the enclosure is unchanged. The initial fuel-air combination has a greater potential than the final warm mixture. The fuel can be used in some device to generate electricity, produce superheated vapor and so on, whereas the uses to which the warm combustion products can be put are far more limited in scope. Since nothing but a final warm mixture is achieved in this process, it can be said that the initial potential has been largely destroyed.

Then what do we need?

We need to conserve the quality of energy or availability of energy. 'Exergy' is the real technical term of quality of energy or availability of energy. So we need to conserve exergy but not energy.

What is Exergy?

Exergy is the maximum work that can be obtained from a given form of energy using the environmental parameters as the Reference State.

The word maximum implies that there are some amounts of work that cannot be extracted. What is it and what happens to this amount? It's called loss of work due to system irreversibility. According to the 2nd law of thermodynamics irreversibility occurs due to system entropy generation. So the concept of exergy is based on the second law of thermodynamics and in practice it relies heavily on the use of thermodynamic property called entropy. All the real thermal processes are irreversible and there exists loss of work and exergy, conserved only in ideal processes, which are thermodynamically reversible.

This loss of work or unconvertible part is called anergy and as discussed earlier, the useful part is exergy. All forms of mechanical energy i.e. kinetic and potential energy, mechanical work and also electrical energy consist of pure exergy because they are in principle totally convertible to any other energy form. In contrast, internal energies and heat involve both exergy and anergy and the internal energy of the environment consist solely of anergy.

The higher the proportion of exergy in every form of energy, the more valuable it is from the technical & economical point of view.

The statements of both the 1st and 2nd law of thermodynamics can be summarized in terms of exergy and energy very clearly as follows.

1st Law - The sum of exergy and energy remain constant during each process.

2nd Law - If a process were reversible, the exergy would remain constant;

if it is irreversible, some exergy is converted to energy. Energy cannot be converted to exergy.

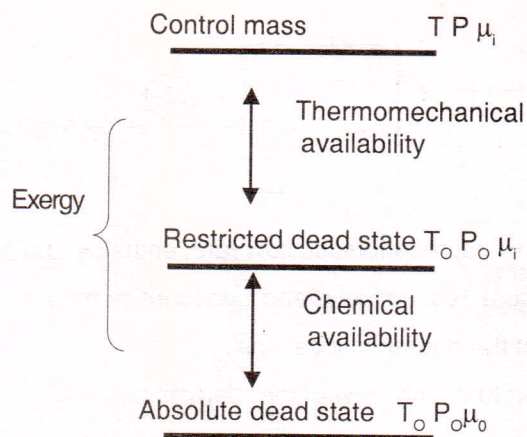
From this it follows that it is exergy rather than energy, which is of concern in all-technical processes. The exergy losses are a quantitatively calculable measure of their effectiveness. The improvement and optimization of a plant design can best be guided by a determination of the sources and magnitudes of its exergy losses.

Each calculation of exergy and thus each exergetic analysis imply reference state called 'dead state'.

If a system is in thermal and mechanical equilibrium with the reference environment that is at the environmental temperature T_0 and Pressure P_0 , it is said to be in a thermodynamically dead state or restricted dead state. In general it is taken as $T_0 = 298 \text{ K}$ and $P_0 = 1 \text{ atm}$.

When the system is in thermal, mechanical and chemical equilibrium with the surroundings, it is called absolute dead state. Thus the concentration is different between the system at restricted dead state and the surroundings at absolute dead state could be used to produce a certain quantity of work called chemical availability.

Chemical exergy is defined as the maximum additional useful work that could be produced by the interaction of the system with the reference environment after it has been brought to the thermo-mechanical dead state.



Exergy at a given state is then calculated by

1. Physical exergy

$$e^{PH} = (h - h_0) - T_0(s - s_0), \text{ where}$$

e^{PH} - exergy

h - enthalpy of substance

s - entropy of the substance at given state and subscript zero represents the reference environment

2. Chemical exergy

$$e^{CH} = -RT_0 \sum y_i \ln (y_i / y_i^e),$$

where y_i and y_i^e denote respectively the mole fraction of component i in the mixture at T_0, P_0 and in the environment. R denotes the universal gas constant.

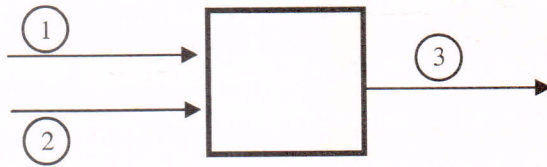
Exergy losses are calculated by making exergy balance for each component of the system. Unlike energy balance where the inflow is equal to outflow (when there is no internal energy generation or consumption), in exergy balance due to reasons of irreversibility, Exergy inflow is always greater than the exergy outflow and their difference gives the exergy loss or exergy destruction. Ratio of exergy output to exergy input gives the exergetic efficiency of a system.

ϵ = exergetic efficiency

$$\epsilon = \frac{\text{Exergy Output}}{\text{Exergy Input}}$$

Consider one example

Two streams of liquid water at $T_1 = 100 \text{ }^\circ\text{C}$ and $T_2 = 40 \text{ }^\circ\text{C}$ are mixed together. The final temperature is T_3 and assume the process is adiabatic. The streams have equal mass flow rates.



m , h and T represent mass flow rate, enthalpy and temperature respectively, and subscript numbers represent the reference locations.

According to the first law of thermodynamics

$$M C_p (T_1 - T_3) = m C_p (T_3 - T_2)$$

$$T_3 = (T_1 + T_2) / 2$$

$$= 70^\circ\text{C}$$

From the thermodynamics data tables

$$h_1 = 344.3 \text{ kJ/kg}, h_2 = 93.2 \text{ kJ/kg}$$

$$h_3 = 218.6 \text{ kJ/kg}$$

$$s_1 = 1.1 \text{ kJ/kg K}, s_2 = 0.321 \text{ kJ/kg K}$$

$$s_3 = 0.732 \text{ kJ/kg K}$$

Specific exergy at the state 1

$$a_{11} = (h_1 - h_0) - T_0 (s_1 - s_0)$$

$$= (344.3 - 42) - 298(1.1 - 0.151)$$

$$= 19.5 \text{ kJ/kg}$$

Similarly

$$a_{12} = 0.242 \text{ kJ/kg}$$

$$a_{13} = 3.46 \text{ kJ/kg}$$

Compare the energy and exergy at each state.

Quantity of energy at the state 01 is 344.4 kJ/kg and the equivalent real availability or the exergy is 19.5 kJ/kg. The energy and exergy levels are quite different in this state and it is due to the system irreversibility. This situation can be seen in the other states also. By these calculations it is realized that the available energy or exergy is always less than the existing energy.

Consider the exergy balance in the above process

$$\text{Total exergy input} = m (19.5) + m (0.242)$$

$$= 19.742m \text{ kJ}$$

$$\text{Total exergy output} = 2m (3.46)$$

$$= 6.92m \text{ kJ}$$

$$\text{Total exergy destroyed} = 19.742m - 6.92m$$

$$= 12.82m$$

The above example indicates that the energy is conserved always in the process but availability or exergy is destroyed.

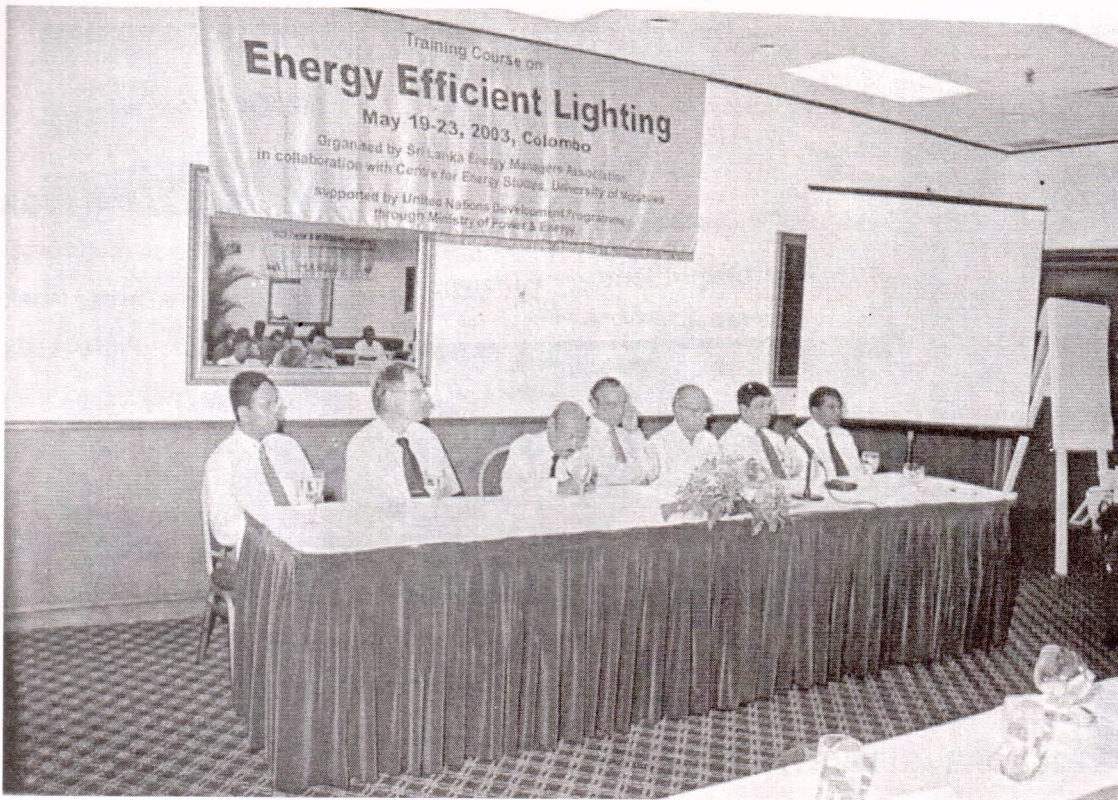
The table below shows typical values of second law (ϵ) and first law (η) efficiencies for selected systems.

Table 1

System	η	ϵ
Thermal power plant	0.41	0.4
Cogeneration power plant	0.75	0.33
Diesel engine	0.40	0.35
Gas turbine	0.35	0.30
Boiler	0.90	0.50
Burner on domestic oven	0.60	0.10
Electric water heater	0.93	0.08
Vapor turbine	0.90	0.50
Electric motor	0.75	0.70
Air conditioning	Cop 2.5	0.70
Refrigerator	Cop 0.9	0.10
Heat pump	Cop 3.5	0.60

It may be observed that the exergetic efficiency is always less than the first law efficiency and for power cycle the exergetic efficiency is very close to the first law thermal efficiency. For some equipment like boilers, burners and electric water heaters, first and second law efficiencies are quite different and it illustrates better understanding of the energy degradation of the processes.

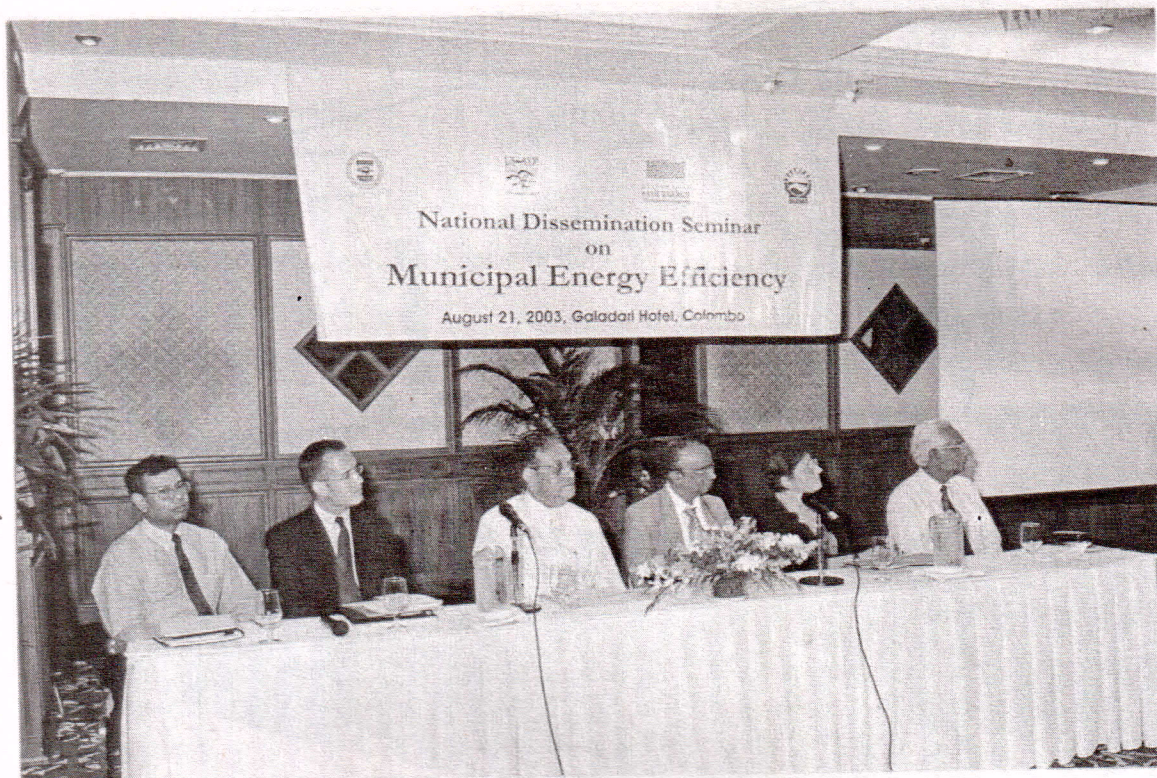
References ???



Inaugural session of Training Course on Energy Efficient Lighting conducted under UNDP project on capacity building –May 2003



President SLEMA handing over a plaque Mr. S. Ranasinghe appreciating his services in the field of Energy Efficient Lighting.



Hon Minister of Power & Energy Karu Jayasuriya inaugurating The Dissemination Seminar on Energy Efficiency in Municipal Services, conducted in August 2003



Talawakele Plantation Limited won a Merit award, awarded by Ceylon Petroleum Corporation under the category of best energy conservation project. The award winning team with the Minister of Power & Energy at SLEMA AGM held on July 2003.