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RESEARCH ARTICLE

EXERGY CONCEPT AND EXERGETIC ANALYSIS: REVIEW

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ABSTRACT

Energy, entropy and exergy concepts come from thermodynamics and are applicable to all fields of science and engineering. Therefore, this article intends to provide background for better understanding of these concepts and their differences among various classes of life support systems with a diverse coverage and a study of these connections and a comprehensive and critical view on the most recent studies on this topic is presented. It also covers the basic principles, general definitions and practical applications and implications in various fields and its characteristic has been discussed and different forms of exergy have been derived. The exergy of an energy form or a substance is a measure of its usefulness or quality or potential to cause change. Exergy is naturally related to the concept of quality of energy. Therefore, exergy analysis has been widely applied in parallel with energy analysis in order to find the most rational use of energy. Also a brief comparison between energy and exergy analysis has been done. Finally, conclusions regarding the usability of the exergy method as a tool to promote a more efficient use of available energy sources are also derived.

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INTRODUCTION

Thermodynamics (from Greek words for *therme*= "heat" and *dynamis* ="power") is the study of heat, work, energy, and the changes they produce in the states of systems. In broader sense, thermodynamics studies the relationships between the macroscopic properties of a system (Levine, 2009). Energy, entropy and Exergy (is the energy that is available to be used) concepts stem from thermodynamics and are applicable to all fields of science and engineering (Rosen, 2007; Dincer, 2001; Pons, 2009). This seminar focuses on the portion of the field of thermodynamics at the intersection of the energy, entropy and exergy fields. Entropy and exergy are also used in other fields (such as statistics and information theory). Also, some forms of energy (such as shaft work) are entropy-free, and thus entropy subtends only part of the energy field. Likewise, exergy subtends only part of the energy field since some systems (such as air at atmospheric conditions) possess energy but no exergy. Most thermodynamic systems (such as steam in a power plant) possess energy, entropy and exergy, and thus appear at the intersection of these three fields (Rosen, 2007; Dincer, 2001; Pons, 2009)

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Energy

Concept of energy

The word energy is derived from the Greek "en"(in or internal) and "ergon"(force or work), energy is motion or ability of motion (Wall, 2009). Energy comes in many forms. Thermodynamics plays a key role in the analysis of processes, systems and devices in which energy transfers and transformations occur. The industrial revolution was fueled by the discovery of how to exploit energy in a large scale and how to convert heat in to work. Nature allows the conversion of work completely in to heat, but heat cannot be entirely converted in to work, and doing so requires a device (e.g. cyclic engine). Engines attempt to optimize the conversion of heat to work. Energy is a scalar quantity that cannot be observed directly but can be recorded and evaluated by indirect measurements. The absolute value of the energy of a system is difficult to measure, where as the energy change is relatively easy to evaluate (Levine, 2009; Rosen, 2007)

Forms of energy

Energy manifests itself in many forms, which is either internal or transient. Energy can be converted from one form to another. In thermodynamic analysis, the forms of energy can be classified in to two groups: macroscopic and microscopic.

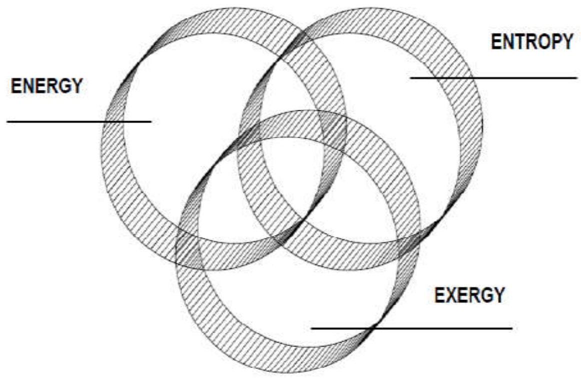

Figure 1 Intersection between the domains of energy, exergy and entropy (Rosen, 2007).

Macroscopic forms of energy:- are those of which an overall system possesses with respect to a reference frame, e.g. Kinetic and potential energies. The macroscopic energy of a system is related to motion and influence of external effects, such as gravity, magnetism, electricity and surface tension. The energy that the system possess as a result of its motion relative to some reference form is kinetic energy. The potential energy of a system is the sum of the gravitational, centrifugal, electrical and magnetic potential energies.

Microscopic forms of energy:- are those related to the molecular structure of a system and the degree of molecular activity, and are independent of outside reference frames. The sum of all the microscopic forms of energy of a system is its internal energy. The internal energy of a system depends on the inherent qualities or properties of the materials in the system, such as composition and physical form as well as the environment variables (temperature, pressure, electric field, magnetic field, etc) (Rosen ,2007; Dincer,2001; Rosen, 2009).

The first law of thermodynamics: The first law of thermodynamics is the law of conservation of energy, which states that, although energy can change form, it can be neither created nor destroyed (Rosen, 2007; Wall, 2009) A change(ΔE) of the system is accompanied by a change in energy of the surroundings equal to -ΔE, so the total energy of a system plus surroundings remains constant (is conserved).[1] However, it provides no information about the direction in which processes can spontaneously occur ,i.e., the reversibility aspects of thermodynamic processes (Levine, 2009)

Energy and the first law of thermodynamics

The total energy E of the body is

$$E = KE + PE + U \qquad ....1$$

Where, *KE* and *PE* are the microscopic (not molecular), *U* is the internal energy of the body (due to molecular motions and intermolecular interactions). For a change of state from state 1 to state 2 with a constant gravitational acceleration ***g*** becomes

$$E_2 - E_1 = U_2 - U_1 + \frac{m}{2}(V_2^2 - V_1^2) + mg(Z_2 - Z_1) \qquad ....2$$

Where, *m* denotes the fixed amount of mass contained in the system, *V* is the velocity, and *Z* is the elevation. The internal energy of a system is an extensive property and thus depends on the amount of matter in the system.

Changing the mass the mass of a system by adding or removing matter, we can change the energy of a system by doing work on it or by heating it.

$$\Delta E = q + W \text{ closed system} \qquad ....3$$

Where ΔE is the energy change under gone by the system in the process, q is the heat flow in to the system during the process and W is the work done on the system during the process.

And $\Delta E_{system} + \Delta E_{surroundings} = 0 = \text{constant}$ 4

When we restrict ourselves to systems at rest in the absence of external fields; E = U, which implies

$$\Delta U = q + W \text{ closed system, at rest, no fields} \qquad ......5$$

Where ΔU is the change in internal energy of a system.

For an infinitesimal process

$$dU = dq + dW \text{ closed system} \qquad .....6$$

Where dU is the infinitesimal change in system's energy in a process, dq is infinitesimal heat flowing in to a system and dW is infinitesimal work done on the system (Levine, 2009; Rosen, 2007)

Entropy

Entropy is a measure of the amount of molecular disorder with in a system. A system possessing a high degree of molecular disorder (such as a high-temperature gas) has a high entropy and vice versa (Levine, 2009; Rosen, 2007; Dincer, 2001).

Characteristics of entropy

Entropy which is a fundamental property relates to the Second law of thermodynamics and has the following characteristics:

- The entropy of a system is a measure of its internal molecular disorder.
- A system can only generate, not destroy, entropy.
- The entropy of a system can be increased or decreased by energy transports across the system boundary.
- Entropy is a measure of order that helps explain the natural direction for energy transfers and conversions.
- Entropy is a randomized energy state unavailable for direct conversion to work (Rosen, 2007; Dincer, 2001)

Second law of thermodynamics

Although a spontaneous process can proceed only in a definite direction, the first law of thermodynamics gives no information about direction; it merely states that when one form of energy is converted to another, the quantities of energy involved are converted regardless of feasibility of the process. The second law of thermodynamics can thus be expressed broadly in terms of entropy as "In any transfer or conversion of energy with in a closed system, the entropy of the system increases". The consequences of the second law can thus be stated as (1) the spontaneous or natural direction of energy transfer or conversion is toward increasing entropy, or (2) all energy transfers or conversions are irreversible. Low-entropy energy sources are normally desired and used to drive energy processes, since low-entropy energy is "useful".

This broader interpretation of the second law of thermodynamics suggests that real "energy conversation" should consider the conservation of both energy quantity and quality (Levine, 2009; Rosen, 2007; Dincer, 2001)

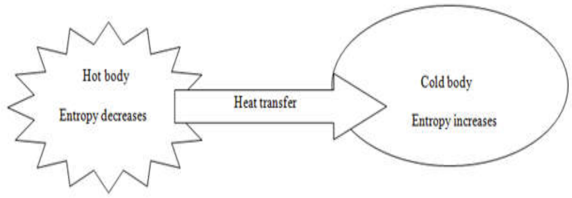

Figure 2. Entropy increase and decrease during heat transfer in hot and cold bodies (Rosen, 2007; Dincer, 2001).

Exergy

The word Exergy has been introduced by Rant (1956) and stems from the Greek words "ex" (meaning "from, out or outer") and "ergon"(meaning "work, force or ordered motion") (Wall, 2009; Hammache, 2002; Noghrehabadi, 2011). Exergy is also known under the names available energy, availability, assergy and technical ability to do work (Hammache, 2002; Gong, 2001).

Definition of exergy

In thermodynamics, the exergy of a system is the maximum useful work possible during a process that brings the system into equilibrium with a heat reservoir or surrounding (Wall, 2009; Gong, 2001; Rosen, 2003). Exergy is a measure that indicates to what degree energy is convertible to other forms of energy (Silow, 2010). The exergy of a system is a measure of its deviation from thermodynamic equilibrium with the environment, and represents the maximum capacity of energy to perform useful work as the system proceeds to equilibrium, with irreversibility increasing its entropy at the expense of exergy (Rosen, 2007). The total exergy of an ecosystem is a measure of the change in entropy content from the equilibrium and the actual state.

Energy = Exergy + Anergy 7

Note: Anergy is the complementary part of the energy that cannot be converted in to work or unavailable energy (Rosen, 2007; Hammache, 2002). Exergy is defined as the amount of work obtainable when some matter is brought to a state of thermodynamic equilibrium with the common components of the natural surroundings by means of reversible process, involving interaction only with the components of the environment (Bayramoglu, 1998; Montelongo, 2011; Bustan, 2011; http://www.exergie.nl/what *is.html,* December 2011; Davidsson, 2011).

Exergy is that part of energy which is off equilibrium; it is the active part of energy that is able to cause change, i.e. do work, generate electricity, heat things up or derive a chemical reaction (Vantovski, 2004; http://solarexergy.com/ index. php? option=comcontent & view=article&id1236 & Itemid688, December 2011; Datta et al., 2007). Exergy is the maximum theoretical work obtainable from the interaction of a system with its environment until the equilibrium state between both is reached and can also be seen as the departure state of one system from that of the reference environment (Noghrehabadi, 2011).

Characteristics of exergy

Some characteristics of exergy include

- A system in complete equilibrium with its environment does not have any exergy. No difference appears in temperature, pressure, concentration, etc.
- The exergy of a system increases the more it deviates from the environment. For instance, a specified quantity of hot water has higher exergy content during the winter than on a hot summer day. A block of ice carries little exergy in winter while it can have significant exergy in summer.
- When exergy loses its quality, exergy is destroyed. Exergy is the part of energy which is useful and therefore has economic value and is worth managing carefully.
- Exergy by definition depends not just on the state of a system or flow, but also on the state of the environment.
- Exergy efficiencies are a measure of approach to ideality (or reversibility). This is not necessary true for energy efficiencies, which are often misleading.
- Energy forms with high exergy contents are typically more valued and useful than energy forms with low exergy. Fossil fuels, for instance, have high exergy and energy contents.
- Waste heat at a near environmental condition, on the other hand, has little exergy, even though it may contain much energy, and thus is of limited value. Solar energy, which is thermal radiation emitted at the temperature of the sun (~5800k), contains much energy and exergy.
- Each form of energy has work potential (i.e. exergy) to produce work.
- Exergy of a system is the sum of all exergies from each form of energy in the system.
- Energy that has a high convertibility potential is said to contain a high share of exergy (Rosen, 2007; Dincer, 2001; Noghrehabadi, 2011).

The reference state/environment

The definition of a reference environment is a premise for exergy calculation. Since the real environment is not totally in thermodynamic equilibrium only common components are often encountered (Hammache, 2002). The environment is often modeled as a reference environment similar to the actual environment in which a system or flow exists. This ability to tailor the reference environment to match the actual local environment is often an advantage of exergy analysis. A standard environment is defined with a specified chemical composition, temperature and pressure (Rosen, 2007; Dincer, 2001). In exergy analysis, the initial state is specified, and thus it is not a variable. The work output is maximized when the process between two specified states is executed in a reversible manner. Therefore all the irreversibilities are disregarded in determining the work potential. Finally, the system must be in the dead state at the end of the process to maximize the work output. A system is said to be in the dead state when it is in thermodynamic equilibrium with the environment. The properties of a system at the dead state are denoted by subscript zero, for example, P_o, T_o, h_o, U_o, and S_o. Unless specified otherwise, the dead sate temperature and pressure are taken to be $T_o = 25\ ^oC$ and P_o=1 atm (101.325 KPa or 14.7 Psi). A system has zero exergy at the dead state. Distinction should be made between the surroundings, immediate surroundings and the environment (Noghrehabadi, 2011).

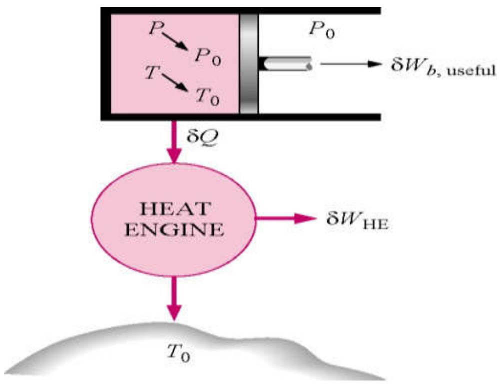

Figure 4. State of a system (Congel, 2001)

By definition, surroundings are everything outside the system boundaries; The immediate surroundings refer to the portion of the surroundings that is affected by the process and the environment refers to the region beyond the immediate surroundings whose properties are not affected by the process at any point. Therefore, any irreversibility during a process occurs within the system and its immediate surroundings, and the environment is free of any irreversibilities. A dead state is when a system at thermodynamic equilibrium with the environment (Noghrehabadi, 2011). The exergy function is a measure of the difference between two states namely the state of the "target" system and that of its surroundings (or more precisely, the ultimate state of the combined system + surroundings, after they have reached mutual equilibrium). Exergy can be calculated without defining appropriate parameters for the environment where the target system operates, interms of temperature, pressure and chemical composition (Ayres, 2001; *http://www.refrigers.com/ content/ view/31961/28/*, December, 2011).

Types of exergy

The different types of exergy can be termed as:

Kinetic exergy:- originating in a difference of velocity between the considered mass flow and the environment (Hammache, 2002; Ayres, 2001). The kinetic exergy (E^{KN}) can be calculated as a function of the considered mass (m) and its velocity (c):

$$E^{KN} = m \cdot e^{KN} = m \cdot \frac{c^2}{2} \quad ....8$$

Potential exergy:- which is associated with a potential of the considered mass flows in a force field (like the gravitational field of the earth) measured in relation to the potential of the environment (Hammache, 2002; Ayres,2001). Potential exergy (E^{PT})is calculated as a function of mass(m), the gravitational acceleration (g) and the altitude(z):

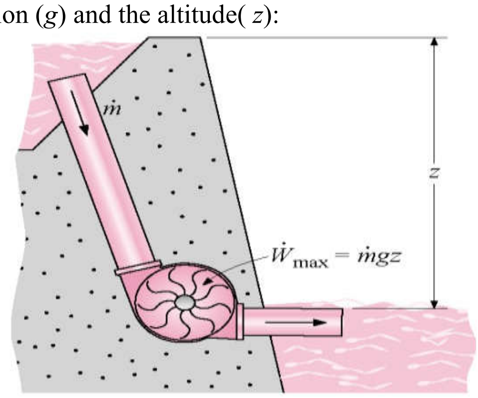

Figure 5. Potential exergy of an engine (Congel, 2001))

Physical exergy:- is the sum of mechanical and thermal exergy

Thermal exergy:- which is a function of the difference in temperature between the flow under consideration and the environment.

Mechanical exergy:- originating in a difference in pressure between the considered transfer and the environment.

Chemical exergy:– is exergy associated with mass flows at reference temperature and pressure due to differences in molecular structure and to differences in concentration. A chemical exergy can further be subdivided in to

Reactive exergy:- which originated from the capacity of a consideration substance that is not part of the environment to react with components of the environment.

Non-reactive exergy:- that is associated with substances that are present in the reference environment but differ from it in concentration (Noghrehabadi, 2011).

Nuclear exergy

Fission exergy-exergy associated with a nuclear fission reaction. fission exergy-exergy associated with a nuclear fission reaction (Hammache, 2002; Koroneos, 2011; Camdali, 2004; Turgut, 2007).

Balances for Mass, Energy, Anergy, Entropy and Exergy

A general balance for a quantity in a system may be written as

Input + Generation − Output − Consumption = Accumulation 10

Input and output refer respectively to quantities entering and exiting through system boundaries. Generation and consumption refer respectively to quantities produced and consumed within the system. Accumulation refers to build up (either positive or negative) of the quantity within the system. Versions of the general balance equation above may be written for mass, energy, entropy and exergy. Consequently, the general balance written for each of these quantities becomes

Mass input − Mass output = Mass accumulation 11

Energy input − Energy output = Energy accumulation 12

Before giving the balance equation for exergy, it is useful to examine that for entropy:

Entropy input+ Entropy generation−Entropy output=Entropy accumulation ...13

Entropy is created during a process due to irreversibilities, but cannot be consumed. These balances describe what is happening in a system between two instants of time. For a complete cyclic process where the initial and final states of the system are identical, the accumulation terms in all the balances are zero (Rosen, 2007; Dincer, 2001; Hammache, 2002; Gong, 2001; Paredos, 2002; Karamakovic , 2010). By combing the conservation law for energy and non-conservation law for entropy, the exergy balance can be obtained, Exergy input ─ Exergy output ─ Exergy consumption = Exergy accumulation ...14

Exergy is consumed due to irreversibilities. Exergy consumption is proportional to entropy action. The above equation tell us energy is conserved while exergy is consumed (Rosen, 2001; Dincer, 2001; Wall, 2009). Energy is the concept to be conserved so that the energy flowing in must be equal to the sum of the energy stored within the system and the energy flowing out from the system. The energy balance can be expressed as,

(Energy input) = (Energy stored) + (Energy output) ...15
If there is no energy storage (at steady state condition),

(Energy input) = (Energy output) ...16

Secondly, let us consider entropy; energy flowing in to the system as heat is more or less dispersed energy. Heat is necessarily flows in to the system as heat flows in and some amount of entropy is generated in envitabliy within the system in the course of heat transmission. The sum of the entropy input and the entropy generated must be in part stored or impart flows out of the system. Therefore, the entropy balance equation can be expressed in the form:

(entropy input) + (entropy generated) = (entropy stored) + (entropy output) ...17

If there is no entropy storage (assuming steady state condition), the entropy balance equation is;

(entropy input) + (entropy generated) = (entropy output) ..18

Combining the energy and entropy balance equations brings about the exergy balance equation. Entropy (or entropy rate) has a dimension of J/K (or W/K) and energy (or entropy rate) has a dimension of J (or W). Therefore, we need a kind of trick to combine the two equations.

We can rewrite the entropy balance equation as;

(entropy input)×T_e + (entropy generated)×T_e = (entropy output)×T_e ...19

Where T_e is the environmental temperature. The product of entropy and environmental temperature is called "anergy", which implies dispersed energy and the anergy balance equation becomes,
(Anergy input) + (Anergy generated) = (Anergy output) ...20

Provided that "anergy" is a portion of energy that is already dispersed, then the other portion is not yet dispersed. In other words, energy consists of two parts; The dispersed part and the part, which cannot disperse. The latter is "exergy". If we take the difference of the two equations, energy balance equation and anergy balance equation. The operation brings about;

((energy input) - (Anergy input)) - (Anergy generated) = ((energy output) - (anergy output)) ...21

"Anergy generated" is such that originally had an ability to disperse and that has just dispersed. In other words exergy is consumed. Anergy generation is equivalent to exergy consumption. So the above can be reduced as:

(exergy input) - (exergy consumed) = (exergy output) ...22

Exergy consumed, is equivalent to anergy generated and is the product of entropy generated and the environmental temperature.

(Exergy consumed) = (environmental temperature) × (entropy generated) ...23

Exergy consumed is exactly proportional to the entropy generated with the proportional constant of environmental temperature (Rosen, 2007; Hammache, 2002; http://www.lowex.net/guidebook/the -exergy-%20approach/the-exergy-%20approach.htm, December 2011).

Exergy efficiencies

Efficiency has always been an important consideration in decision making regarding resource utilization. Efficiency is defined as 'the ability to produce a desired effect without waste of, or with minimum use of, energy, time, resources, etc.,' and is used by people to mean the effectiveness with which something is used to produce something else, or the degree to which the ideal is approached in performing a task. Ratios of energy are conventionally used to determine efficiencies of engineering systems whose primary purpose is the transformation of energy. These efficiencies are based on the first law of thermodynamics. A process has maximum efficiency according to the first law if energy input equals recoverable energy output (i.e., if no 'energy losses' occur). However, efficiencies determined using energy are misleading because in general they are not measures of 'an approach to an ideal (Rosen, 2007). To determine more meaningful efficiencies, a quantity is required for which ratios can be established which do provide a measure of an approach to an ideal. Thus, the second law must be involved, as this law states that maximum efficiency is attained (i.e., ideality is achieved) for a reversible process (Rosen, 2007; Hammache, 2002). Exergy efficiency is defined as utilized exergy divided by the exergy which is theoretically possible to utilize. From energy and exergy viewpoints, a gauge of how effectively the input is converted to the product is the ratio of product to input (Rosen, 2007; Dincer, 2001; Davidsson, 2011; Ji, 2006).

That is, energy efficiency η can be written as,

$$\eta = \frac{\text{Energy out put in product}}{\text{Energy input}} \quad .....24$$

And the exergy efficiency η_{ex} as,

$$\eta_{ex,1} = \frac{E_{out}}{E_{in}} \quad ...25$$

where E_{out} is the exergy out put

E_{in} is the exergy input. A part of the output is how ever is usually waste.

$$E_{out}=E_{pr}-E_{waste} \quad ...26$$

Where E_{pr} is the exergy of the product and E_{waste} is the exergy of waste.

Which gives

$$\eta_{ex,2} = \frac{E_{out} - E_{waste}}{E_{in}} = \frac{E_{pr}}{E_{in}} = \eta_{ex,1} - \frac{E_{waste}}{E_{in}} \quad ...27$$

Table 1. Comparison of energy and exergy (Rosen, 2007; Dincer, 2001; Davidsson, 2011)

Energy	Exergy
Is motion or ability to produce motion.	Is work or ability to produce work.
Is dependent on properties of only matter or energy flow, and independent of environment properties.	Dependent on properties of both a matter or energy flow and the environment.
Has values different from zero when in equilibrium with the environment (including being equal to mc^2 in accordance with Einstein's equation).	Equal to zero when in the dead state by virtue of being in complete equilibrium with the environment.
Is governed by the first law of thermodynamics for all process.	Is governed by the second law of thermodynamics for reversible processes (in real or irreversible processes it is partly or completely destroyed).
Is limited by the second law of thermodynamics for all processes (including reversible ones).	Is not limited for reversible processes due to the second law of thermodynamics.
Is always conserved in a process, so can neither be destroyed or produced.	is always conserved in a reversible process, but is always consumed in an irreversible process.
Can neither destroyed nor produced. Energy is always conserved, i.e. in balance it can neither be produced nor consumed.	Can be neither destroyed nor produced in a reversible process, but is always destroyed (consumed) in an irreversible process. Exergy is always conserved in a reversible process but reduced in an irreversible process, i.e. real processes. Thus, exergy is never in balance for real processes.
Appears in many forms(eg. Kinetic energy, potential energy, work, heat) and is measured in that form.	Appears in many forms (eg. Kinetic exergy, potential exergy, work, thermal exergy) and is measured on the basis of work or ability to produce work.
Is a measure of quantity only.	Is a measure of quantity and quality due to entropy.

It is also possible for some exergy to be transit exergy, E_{tr}, that passes through the system unaffected,

$$\eta_{ex,3} = \frac{E_{out} - E_{waste} - E_{tr}}{E_{in} - E_{tr}} = \frac{E_{pr} - E_{tr}}{E_{in} - E_{tr}} \quad ...28$$

So exergy efficiency gives a finer understanding of performance than energy efficiency (Dincer, 2001; Montelongo, 2011; Ji, 2006; Alsairafi, 2011).

Exergy efficiencies are classified as,

1st law efficiency

2nd law efficiency

1st law efficiency:- is a measure of performance of a device and it does not relate to its best possible performance.

$$1^{st}\ \text{law efficiency} = \frac{\text{Desired out put}}{\text{Required input}} \quad ...29$$

2nd law efficiency:- is a measure of performance of a device relative to its best possible performance for the same end states.

$$\eta_{II} = \frac{W_u}{W_{rev}} \text{ for work producing device} \quad ...30$$

$$\eta_{II} = \frac{W_{rev}}{W_u} \text{ for work consuming device} \quad ...31$$

Exergy efficiencies are described as an efficiency based on the second law of thermodynamics and is used to gauge the performance of devices and processes. Exergy based or second law of thermodynamics based efficiency which gives a finer understanding of performance can be expressed as (Rosen, 2007; Dincer, 2001; Hammache, 2002; Montelongo-Luna, 2011; Davidsson, 2011),

(Exergy in) = (Exergy output in product) + (Exergy emitted with waste) + (Exergy destruction)

$$\text{Exergy efficiency}(\eta_e) = \frac{\text{Exergy output in product}}{\text{Exergy input}} \quad ....32$$

$$= 1 - \frac{[\text{Exergy loss}]}{[\text{Exergy input}]} \quad ...33$$

$$= 1 - \left[\frac{\text{Exergy waste emission + exergy destruction}}{\text{Exergy input}}\right] \quad ...34$$

$$2^{nd}\ \text{law of thermodynamics based efficiency} = \frac{\text{The sum of the exergy exiting}}{\text{The sum of the exergy entering}} \quad ...35$$

Exergy analysis

Exergy analysis is a thermodynamic analysis technique based on the second law of thermodynamics which provides an alternative and illuminating means of assessing and comparing processes and systems rationally and meaning fully (Rosen, 2007; Dincer, 2001; Rosen, 2003). Exergy has the characteristic that is conserved only when all processes occurring in a system and the environment are reversible. Exergy is destroyed whenever an irreversible process occurs. When an exergy analysis is performed on a plant such as a power station, a chemical processing plant or a refrigeration facility. The thermodynamic imperfections can be quantified as exergy destructions, which represent losses in quality or usefulness (e.g. Wasted shaft work or wasted potential for the production of shaft work). Like energy, exergy can be transformed or transported across the boundary of a system. For each type of energy transfer or transport there is a corresponding exergy transfer or transport. Exergy analysis takes in to account the different thermodynamic values of different energy forms and quantities, e.g. Work and heat. The exergy transfer associated with shaft work is equal to the shaft work. The exergy transfer associated with heat transfer, however depends on the temperature at which it occurs in relation to the temperature of the environment (Rosen, 2007; Dincer, 2001; Hammache, 2002).

Exergy analysis is an effective method and tool for

- Combining and applying the conservation of mass and conservation of energy principles together with the SLT for the design and analysis of energy systems.

- Improving the efficiency of energy and other resource use (by identifying efficiencies that always measure the approach to ideality as well as the locations, types and true magnitude of wastes and losses).
- Revealing whether or not and by how much it is possible to design more efficient systems by reducing the in efficiencies in existing systems.
- Addressing the impact on the environment of energy and other resource utilization, and reducing or mitigating that impact.
- Identifying whether a system contributes to achieving sustainable development or is unsustainable (Rosen, 2007; Dincer, 2001).

Procedures for exergy analysis

A simple procedure for performing energy and exergy analysis involves the following steps:

- Subdivide the process under consideration in to as many sections as desired, depending on the depth of detail and understanding desired from the analysis.
- Perform conventional mass and energy balances on the process, and determine all basic quantities (e.g. work, heat) and properties (e.g. temperature, pressure).
- Based on the nature of the process, the acceptable degree of analysis complexity and accuracy, and the questions for which answers are sought, select a reference environment model.
- Evaluate energy and exergy values, relative to the selected reference environment model.
- Perform exergy balances, including the determination of exergy consumptions.
- Select efficiency definitions, depending on the measure of merit desired, and evaluate values for the efficiencies.
- Interpret the results, and draw appropriate conclusions and recommendations, relating to such issues as design changes retrofit plant modifications, etc (Rosen, 2007; Dincer, 2001).

Exergy and Energy

Energy analysis is the traditional method of assessing the way energy is used in an operation involving the physical or chemical processing of materials and the transfer and/or conversion of energy. This usually entails performing energy balances, which are based on the first law of thermodynamics, and evaluating energy efficiencies. This balance is employed to determine and reduce waste exergy emissions like heat losses and sometimes to enhance waste and heat recovery. However, an energy balance provides no information on the degradation of energy or resources during a process and does not quantify the usefulness or quality of the various energy and material streams flowing through a system and exiting as products and wastes. The exergy method of analysis overcomes the limitations of the first law of thermodynamics. The concept of exergy is based on both the first law of thermodynamics and the second law of thermodynamics. Exergy analysis clearly indicates the locations of energy degradation in a process and can therefore lead to improved operation or technology. Exergy analyses can also quantify the quality of heat in a waste stream.

A main aim of exergy analysis is to identify meaningful (exergy) efficiencies and the causes and true magnitudes of exergy loses. It is important to distinguish between exergy and energy in order to avoid confusion with traditional energy based methods of thermal system analysis and design. Energy flows into and out of a system with mass flows, heat transfers, and work interactions (eg. Work associated with shafts and pistons rods). Energy is conserved, in line with the first law of thermodynamics. Exergy, although similar in some respects is different. It loosely represents a quantitative measure of the usefulness or quality of an energy or material substance. More rigorously, exergy is a measure of the ability to do work (or the work potential) of the great variety of streams (mass, heat, work) that flow through a system. A key attribute of exergy is that it makes it possible to compare on a common basis interactions (inputs, outputs) that are quite different in a physical sense.

Another benefit is that by accounting for all the exergy streams of the system it is possible to determine the extent to which the system destroys exergy. The destroyed exergy is proportional to the generated entropy. Exergy is always destroyed in real processes, partially or totally, in which the second law of thermodynamics. The destroyed exergy or the generated entropy, is responsible for the less-than-ideal efficiencies of systems or processes (Rosen, 2007; Dincer, 2001). In order to describe the difference between energy and exergy the concept of anergy has been introduced;

$$A' = W - E \qquad \text{...36}$$

Where A' is anergy, W is energy and E is exergy.

It is important to notice that anergy may be negative, i.e., when the exergy is larger than the energy, as for cold systems or systems at low pressure. Thus, anergy is not a commonly accepted or needed concept. (Paredos and Kitanovski, 2002)

Conclusion

The basis of thermodynamics is stated in the first and second laws. The first law is concerned with the conservation of energy, whereas the second law is concerned with the dissipation of energy. The second law, allows energy quality levels to be quantitatively valued. It also asserts that accessible work potential is always lost in any real process, and provides a measure of the loss in all real energy transformation processes, Exergy is not subject to a conservation law, but can be lost when or where the quality of energy is degraded, due to irreversibility in any process. Exergy analysis is a method that applies the conservation of mass and conservation of energy principles together with the second law of thermodynamics for the design and analysis of energy systems. The exergy method can be suitable for furthering the goal of more efficient energy resource use, for it enables the locations, type and true magnitudes of wastes and losses to be determined.

Unlike energy, exergy is not subject to a conservation law (except for ideal, or reversible, processes). Rather exergy is consumed or destroyed, due to irreversibilities in any real process. The exergy consumption during a process is proportional to the entropy created due to irreversibilities associated with the process. For exergy analysis, the state of the reference environment, or the reference state, must be specified completely.

This is commonly done by specifying the temperature, pressure and chemical composition of the reference environment. The results of exergy analyses, consequently, are relative to the specified reference environment, which in most applications is modeled after the actual local environment. In general, more meaningful efficiencies are evaluated with exergy analysis rather than energy analysis, since exergy efficiencies are always a measure of the approach to the ideal. Therefore, exergy analysis can reveal whether or not and by how much it is possible to design more efficient energy systems by reducing the inefficiencies in existing systems.

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