CANADIAN CONSULTING engineer

Exergy

Many of modern society's most pressing issues concern the subject of energy. Policy makers are constantly debating it while people are consuming ever-increasing amounts of it. Engineers and scientists...

April 1, 2005 By Marc A. Rosen, Ph.D., P.Eng.

Many of modern society's most pressing issues concern the subject of energy. Policy makers are constantly debating it while people are consuming ever-increasing amounts of it. Engineers and scientists are continually trying to find new and better methods of delivering and using it. Energy and energy systems issues are at the core of many sociopolitical, economic and environmental debates.

Improvements in the costs, environmental characteristics and reliability of energy resources have the potential to increase living standards and improve the economic prosperity of poor countries. They can also improve basic sanitation and health care, and reduce the amount of pollutants entering our environment.

But many argue it is not energy, but rather exergy, that is of interest in such discussions. This view has evolved over many years, and stems from the fact that exergy almost always correlates with commodities that we value, while energy is simply a scientific quantity that is conserved.

Although applications and analysis tools based on exergy are relatively new, it surprises many to learn that the history of exergy goes back almost two centuries. In this article, I will provide an overview of what exergy is and how it is being applied today with the objective of helping to make it more widely accepted.

True value

It is often contended that the commodity sought after because it can drive processes and devices is not energy, but rather exergy.

Exergy, in simple terms, is the optimal work that can be extracted from a system as it interacts with an environment. It is this commodity, exergy, which provides the potential to cause change and it is exergy that engineers and scientists strive to deliver. In contrast, energy is simply a commodity that is conserved during processes and may or may not provide a potential to cause change.

Exergy derives from both the first and second laws of thermodynamics, with a focus on the second law. Hence, an analysis based on exergy is often referred to as second-law analysis.

Exergy is associated with materials and energy forms (such as heat, electricity, work). It is evaluated relative to a conceptual environment.

Thus, for example, the exergy of the matter in a closed system can be expressed as the sum of physical exergy, chemical exergy, kinetic exergy and potential exergy. Kinetic and potential exergy are normally equal to kinetic and potential energy, respectively. Physical exergy is the maximum work obtainable from a system as it is brought to thermal and mechanical equilibrium with the reference environment. Chemical exergy is the maximum work obtainable from a system as it is brought from that state to complete equilibrium with the environment.

Using exergy and related ideas, a powerful tool known as exergy analysis has been developed. Exergy analysis aids engineers and scientists in analyzing and optimizing energy systems and energy-intensive processes.

Using exergy analysis

When exergy analysis is applied, the exergy associated with each flow of material and/or energy within a system is evaluated. Then exergy balances are applied to the overall system, and subsystems, so as to determine losses and evaluate efficiencies.

A general balance equation may be written for exergy:

Exergy / input – Exergy / output – Exergy / consumption =Exergyaccumulation

Exergy is consumed due to irreversibilities. Exergy consumption is proportional to entropy creation. An important difference between energy and exergy is that energy is conserved while exergy, a measure of energy quality or work potential, can be consumed and therefore is not conserved. This balance can describe what is happening in a system between two instants of time or at an instant in time.

Tadeusz Kotas wrote in the preface to his 1995 book on exergy, "ever since the … early 70s, there has been a steady growth in the interest in exergy analysis…. This increase manifests itself in … the more widespread use of exergy analysis in industry."

Exergy analysis has been applied to many different fields (e.g. chemical processing, combustion, power generation with fuel cells, energy storage), primarily as a tool for thermodynamic assessment, optimization and design, and for energy management. Exergy methods now allow scientists and engineers to analyze resource use and efficiency much more effectively than energy analysis alone.

Some electrical generation companies, for example, use exergy methods to design better stations, and to improve efficiency or avoid deteriorating performance in existing stations. Also, some cogeneration (or combined heat and power) facilities use exergy methods both to improve efficiency and to resolve economic costing and pricing issues.

In addition, exergy analysis has been extended beyond the realm of thermodynamics into such areas as exergy-related economics and economic resource theory, information theory, environmental impact prediction and sustainability. Some propose that, for the benefit of society, government energy policy should be based on rigorous exergy methods.

Engines, heaters and thermal storage

Many examples illustrate how exergy analysis can be used and how it clarifies measurements of thermodynamic efficiency and loss. Three are presented here.

***** An engine. Consider a Carnot heat engine operating between a heat source at a temperature of 600 K and a heat sink at 300 K. The energy efficiency of this device is 50% (i.e. 1 – 300/600 = 0.5). Yet a Carnot engine is ideal. Clearly, the energy efficiency is misleading as it indicates that a significant margin for improvement exists when in fact there is none. The exergy efficiency of this device is 100%, properly indicating its ideal nature in a straightforward and clear manner.

* An electric heater. For an electrical resistance space heater, almost all of the electricity that enters the unit is dissipated to heat within the space. Thus the energy efficiency is nearly 100% and there are almost no energy losses. Yet the exergy efficiency of such a device is typically less than 10%, indicating that the same space heating can in theory be achieved using one-tenth of the electricity. In reality, some of these maximum savings in electricity use can be attained using a heat pump. The use of even a relatively inefficient heat pump can reduce the electricity used to achieve the same space heating by one-third. Clearly the use of energy efficiencies and losses is quite misleading for electrical heating.

* Thermal storage tank. Consider a buried thermal energy storage tank, which undergoes three operating phases. A hot medium flows through a heat exchanger within the storage tank and heat is transferred into the tank. After a period of time, a cold fluid is run through the heat exchanger and heat is transferred from the storage tank into the cold fluid. The amount of heat thus recovered depends on how much heat has escaped from the storage tank into the surrounding soil, and how long the recovery fluid is passed through the heat exchanger. But a problem arises in evaluating the energy efficiency of this storage tank because the energy efficiency can be increased simply by lengthening the time that the recovery fluid is circulated. What is neglected here is the fact that the temperature at which the heat is recovered is continually decreasing towards the ambient soil temperature as the fluid circulates. Thus although the energy recovered increases as the recovery fluid continues to circulate, the exergy recovered hardly increases at all after a certain time, reflecting the fact that recovering heat at near-environmental temperatures does not make a storage tank more efficient thermodynamically.

Benefits

The benefits of exergy analysis are clearly identifiable and sometimes they are remarkable:

***** Efficiencies based on exergy, unlike those based on energy
, are always measures of the approach to true ideality, and therefore provide more meaningful information when assessing the performance of energy systems.

***** Exergy losses clearly identify the locations, causes and sources of deviations from ideality in a system.

***** In complex systems with multiple products (e.g. trigeneration plants that simultaneously produce electricity, heat and cooling), exergy methods can help evaluate the thermodynamic values of the product energy forms, even though they normally exhibit radically different characteristics.

***** Exergy-based methods have evolved that can help in design-related activities. For example, some methods (e.g. exergoeconomics and thermoeconomics) can be used to improve economic evaluations. Other methods (e.g. environomics) can assist in environmental assessments.

Exergy has matured to the point where, in 2004, the International Journal of Exergy was launched by Inderscience Publishers (www.inderscience.com). This carried on from the publication by Elsevier of Exergy, an International Journal from 2001-02. Work continues to this day on expanding exergy's applications, to thermodynamic processes and beyond, with the objective of benefiting society.

Marc A. Rosen, Ph.D., P.Eng is professor and founding dean of the Faculty of Engineering and Applied Science at the University of Ontario Institute of Technology in Oshawa, Ontario. He is past-president of the Canadian Society for Mechanical Engineering. This article incorporates sections from an article "Exergy and its History," *that appeared in the CSME Bulletin, Fall 2004, co-authored by Marc Rosen with Peter Rezac and Hameed Metghalchi of the mechanical and industrial engineering dept., Northeastern University, Boston, Massachusetts.*

References

Moran, M. J., Availability Analysis: A Guide to Efficient Energy Use. American Society of Mechanical Engineers, 1989.

Kotas T. J., The Exergy Method of Thermal Plant Analysis. Reprint edn., Krieger, Malabar, FL, 1995.

Rosen, M. A. and Dincer, I., "Exergy as the confluence of energy, environment and sustainable development." Exergy, An International Journal 1:3-13, 2001.

Berg, C.A., "Process Integration and the Second Law of Thermodynamics: Future Possibilities." Energy — The International Journal 5, 1980.