BOOK REVIEW

J.SZARGUT *EXERGY METHOD: Technical and Ecological Applications*, WIT Press, Southampton, Boston, 2005, 164 pages.

I learned the word "exergy", born exactly 50 years ago, from the book by Prof. J. Szargut published in Poland in 1965 and translated into Russian by V. Brodianski (eminent proponent of the concept) in 1968. Since that time, I have told my students, "When we say "to produce energy" or to "conserve energy" it does not mean that we ignore the First Law of energy conservation. We simply need to think here "exergy**"** instead of "energy". Please study the book by Prof. Szargut and you will know how to calculate it.

About 20 years later, another eminent exergy proponent, G. Wall, compiled more than 2000 papers on exergy. Among them, the most productive author was Prof. Szargut. Now, 40 years later, we have an excellent opportunity to learn about recent achievements in this area in his book which is reviewed here.

Let us look at the author's formulation of the book's contents:

- *Calculations of the chemical exergy of all stable chemical elements,*
- *global natural and anthropogenic exergy losses, practical guidelines for improvements of the thermodynamic imperfections of thermal processes,*
- *methods for determining partial exergy losses in thermal systems,*
- *thermo-ecological costs,*
- *a general method for optimizing the operational and design parameters with the goal of minimizing the depletion of non-renewable natural resources,*
- *sustainability index of the natural environment,*
- *evaluation of the natural mineral capital of the Earth,*
- *determination of a pro-ecological tax as a substitute for existing personal taxes.*

Quite naturally, all the above mentioned items are treated on an exergy basis.

It should be stressed here that in studying the exergy concept, the so-called "physical" part of the exergy, which depends on pressure and temperature, is fairly easily understood. The Carnot factor converts a heat interaction into an exergy one. The principal difficulties of understanding the exergy concept, especially for mechanical engineers, are those related to chemical processes. A well-developed understanding of thermo-chemistry is not very prevalent in the mechanical engineering even though a very central process to energy systems - combustion - belongs precisely to the need to understand the thermo-chemistry.

It is not exaggerated to state that all of the science of chemical exergy has been created by Prof. Szargut and his school. It is described in the book in compressed form with many updated tables of numerical data, including a table of the standard chemical exergy for about 250 pure substances. The book can be used as a handbook on chemical exergy. At the same time, the book is a good textbook as it contains many exercises with detailed solutions at the end. Let us consider only one example, namely,

2.8. Calculate the standard free energy increase for the reaction

$$CaO + SO_2 + 0.5\ O_2 \Rightarrow CaSO_4$$

Using the values of standard chemical exergy cited in table 1, the solution is that the standard chemical exergy of a chemical compound (Equation (2.7)) is

$$0 = -\Delta G^0 + \sum B_{chp}{}^0 - \sum B_{chr}{}^0$$

where ΔG^0 is the standard free energy of reaction and the summations are the sums of the normal standard chemical exergies of the effluent and influent reference species, respectively. Thus,

$$\Delta G^0 = 24.9 - 313.4 - 0.5x3.97 - 110.2 = -417.4\ kJ/mol$$

This example shows that one could compare this result with other handbooks in thermo-chemistry where only the free energies of reactions are given.

The book describes the exergy analyses of metallurgical units, which were primarily developed by author and his school. Here, a clear understanding of the chemical exergy plays a major role. Such an understanding is very important since metallurgy consumes only a bit less fuel than power plants and discharges even more pollution.

The list of twenty recommendations on how to improve the thermodynamics of a project which appears in the book is useful for students. One of the best examples of the practical use of the exergy method may be the very detailed description of optimizing tube type water preheater. The minimum of the annual exergy consumption versus Reynolds number is quite striking. In a similar optimization of shell-and-tube water preheater, the operational (current) and invested exergy expenditures are clearly defined.

Most important for the decision-making process is the pro-ecological tax proposed by author, which is *proportional to the cumulative consumption of non-renewable primary exergy*. If implemented, it would stimulate the conservation of the primary resources of mankind.

So far so good. Now, I wish to show what has been left undiscussed even though it is possible to do so clearly on an exergy basis. By no means is this a reproach of the author. Simply put, readers should know what it is that they cannot find in this book on exergy. Accordingly, I will indicate what I could not understand as well as some of my disagreements.

In most practical cases, exergy takes part in transfers (flows) of mass, impulse, and energy. Flows are the principal subjects of Non-equilibrium Thermodynamics where equilibrium is assumed only locally in small volumes. But for every flow, there exists a vector describing the flow direction. In the book by Prof. Szargut, there is not a single word about the exergy vector and its associated differential local balance equation.

The author has developed in detail the concept of cumulative exergy, a concept very important for the life cycle analysis of every energy unit. He properly distinguishes in Equation (3.12) expenditures for each unit (invested exergy) from those used by each unit (operational exergy). The denominator in the total (cumulative) exergy efficiency is the sum of invested and currently consumed exergy. The graphical history of the exergy flow of every energy unit begins with a negative part, which reflects the invested exergy. After a unit has been constructed and starting with normal operation, the positive (delivered) exergy flow appears, which is simply the numerator of the total exergy efficiency.

In discussing some of the exergy losses which should be accepted in order to reduce capital investment, the author states that “accepting exergy loss should always have some economic justification”. I disagree here with the word “economic”. Such a justification might be purely thermodynamic if, for example, some of the operational exergy losses were to decrease the invested exergy which in turn increased the total exergy efficiency. This relates directly to the rule for improving imperfections on pages 2 and 76.

The invested exergy concept makes it easy to explain why the Carnot cycle is impossible, i.e. when temperature difference for heat exchange goes to zero, the heat transfer surface area goes to infinity along with the invested exergy. Hence, the total exergy efficiency of the Carnot cycle goes to zero.

The concept of thermo-ecological cost (TEC) introduced in the book is worthy of special attention. The definition given on page 91 is that the TEC is the cumulative exergy consumption of non-renewable natural resources. As every cost, it is expressed numerically per unit of product. On the page 100 some examples are given: For coke the TEC = 49.6 MJ/kg, for iron ore 4.5 MJ/kg, for liquid pig iron 32.2 MJ/kg, for electricity 3.13 MJ/MJ. The question is “why is the TEC not dimensionless?” Simple logic suggests measuring the product in terms of its exergy content, leading to a dimensionless criterion similar to the inverse total efficiency CExC in table 3.1. For electricity, it is evidently 3.13, for coke it is 1.45 (assuming coke as a pure carbon with a chemical exergy of 410.26 kJ/mol). This criterion **Z = cumulative exergy consumption/delivered exergy** has been given on the page 56 along with some examples of optimization in rather general form in the book by the reviewer entitled *Energy and Exergy Currents* (1994). It is indicated as the main criterion of Exergonomics. I believe that transforming the values of the TEC given in Prof. Szargut’s book into values of Z would shed some light on many problems.

As to the determination of human work in exergy terms (page 114), the author defines it as follows: "*the total exergy cost of human work should be equal to the total consumption of non-renewable exergy"*. This I do not understand. I think that the exergy of human work is a combination of physical work (force times distance) and the flow of informational exergy processed by the worker. The link of exergy to information, treated as negative entropy, has been mentioned by many authors, including the reviewer. Still the concept is in its infancy and words written do not necessarily transform themselves into calculations. However, the simple attribution of the total consumption of non-renewable exergy in the TEC calculations to the total amount of work-hours (mean specific value) looks like it is the calculation of the mean temperature of patients in a hospital. In any optimization, the TEC should not be used twice.

I have not said a word about the link between exergy and monetary units. It is my particular view, not shared by many colleagues, that the involvement of monetary prices is not compatible with exergy analysis. The latter has a firm physical basis since it can be shown by experiment. The data of cumulative exergy given by Prof. Szargut will be valid for many years. They are sensitive to technology changes only. Such changes, which occur rarely do necessitate updating the cumulative exergy tables. However, which prices should a designer of a refinery keep in mind, say in 1973, when oil prices suddenly quadrupled and then some years later returned back to their earlier values? Since monetary costs are linked to prices, they base on an unreliable foundation. I believe, that an economic analysis, which is crucial for decision making, should be done separately after the thermodynamic one. The cost of a turbine unit depends on many factors, but it needs to be efficient beforehand. Quite similarly the purely thermodynamic TEC or Z or CexC criterions are needed for subsequent economic analyses. From economics one might take the concept of discounting exergy as is done with money, but the consensus of the exergy-minded practitioners would be needed.

Finally, in spite of the rather long 50 years life of the concept of *exergy*, the concept continues to be ignored not only by many decision-makers but some energy engineers as well. This can lead to erroneous decisions in policy and design. The remedy is to attentively read the excellent book on the exergy method by Prof. Jan Szargut.

Evgeny Yantovski
Independent Researcher, Elsass-Str. 58,
D52068 Aachen, Germany
E-mail: iksvotnay@aol.com