Exergy Analysis

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According to popular impressions, all real processes involve energy losses. However, such an interpretation is not satisfactory from the logical point of view - since energy is bound by the law of conservation, it cannot be destroyed

A deeper analysis reveals that in real processes energy is not destroyed, but rather transformed into other forms, less suitable for feeding and driving real processes. Hence, besides energy, another physical quantity should be introduced to characterize the quality of the kind of energy under consideration. The ability to perform useful work in a natural environment has been suggested and investigated as a measure of energy quality by Gibbs, A. Stodola, G. Gouy, J.H. Keenan, F. Bosnjakovic and many other researchers. Z. Rant in 1956 proposed the term *exergy*, which has since been broadly accepted. This marked the beginnings of a new branch of thermodynamics, which developed mainly in Europe in the 1950s and later worldwide. Polish researchers (connected mainly with the Silesian University of Technology) are also among the pioneers of this new branch. The present author first applied the term *energy potential* and later adopted the term suggested by Rant. Many researchers maintain that the concept of exergy should be introduced into the middle level of school education, because it facilitates a proper understanding of the law of energy conservation.

Exergy analysis is based upon the second law of thermodynamics, which stipulates that all macroscopic processes are irreversible. Every such irreversible process entails a non-recoverable loss of exergy, expressed as the product of the ambient temperature and the entropy generated (the sum of the values of the entropy increase for all the bodies taking part in the process). Some of the components of entropy generation can be negative, but the sum is always positive.

The elementary irreversible phenomena that generate entropy are: mechanical or hydraulic friction, heat transfer with a finite temperature gradient, diffusion with a finite gradient of concentration, and the mixing of substances with different parameters and chemical composition. Combustion is also a typical irreversible phenomenon; however, it is a complex process comprising all the abovementioned elementary irreversibilities.

Every exergy loss causes a decrease in the useful effect of a given process or increased consumption of the means that drive it. Therefore, Bosnjakovic called upon researchers to work to fight irreversibilities. However, the reduction of exergy losses usually requires some investment expenditures. Sama noticed that exergy losses are acceptable if they reduce the investment expenditures. Bosnjakovic's appeal should therefore be supplemented: fighting irreversibilities is desirable, but within the limits of economic profitability.

The analysis of exergy losses identifies possibilities for improving thermal processes and helps select a rational scheme for thermal systems. The need to reduce the losses caused by friction is evident; however, the possibility of reducing the losses due to irreversible heat transfer are not always obvious, because this can sometimes be attained by modifying the scheme of a thermal plant. For example, in a combined power plant equipped with a coal boiler and

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In every thermal power plant a considerable fraction of the fuel energy is transformed into the energy of cooling water, which is rejected to the environment in cooling towers. However, such rejected waste heat is worthless and its rejection does not lower the energy efficiency of the power plant. The main causes of the generation of waste heat act inside the steam boiler gas turbine, the heat transfer exergy losses in the heat recovery boiler of the gas turbine can be reduced by shifting the steam superheater from the coal boiler to the heat recovery boiler of the gas turbine. Another example can be taken from the chemical industry, where a flow of exhaust raw material from chemical reactions is recirculated to the initial links of the process. Recirculation always denotes an exergy loss resulting from the mixing of exhaust raw material with rich, fresh raw material. Recirculation always increases the number of steps in the process.

Can exergy be used in economic calculations?

The specific cost of producing useful exergy increases over the course of energy transformations. This effect results from the following causes: the amount of useful exergy decreases because of unavoidable irreversibilities, and at every link in the considered process a new component of fixed costs appears, resulting from investment expenditures for the considered link.

These considerations stimulated the formulation of concepts about the economic applications of exergy. A new branch of exergy analysis has been developed in the last 3 decades, called thermoeconomy or exergonomics. Hundreds of publications and numerous books have been published in this field. However, in the opinion of the present author, exergy is a thermodynamic quantity, not an economic one. Exergonomic theories are always based on some conventional assumptions, not always consciously formulated. For example, there are suggestions for exergy to be applied to the partition of production costs in cogeneration processes producing two or more useful products simultaneously. These suggestions result from the assumption that the specific production cost (per exergy unit) is the same for all the useful products of a cogeneration process. Nevertheless, this assumption does not follow from any scientific law. It is worth stressing that the methods of economic analysis and optimization are sufficiently developed and need not be replaced by exergetic methods. Moreover, a purely economic principle of cost partitioning in the cogeneration process does exist, namely the principle of avoided expenditures. The production cost of a useful by-product should be evaluated according to the production costs that can be avoided in the overall system, thanks to the utilization of this by-product of the cogeneration process. The utilization of such a by-product supplants the production of the product of some specialized process. For example, the utilization of electricity from a heat-and-power plant supplants some portion of electricity production at condensation power plants.

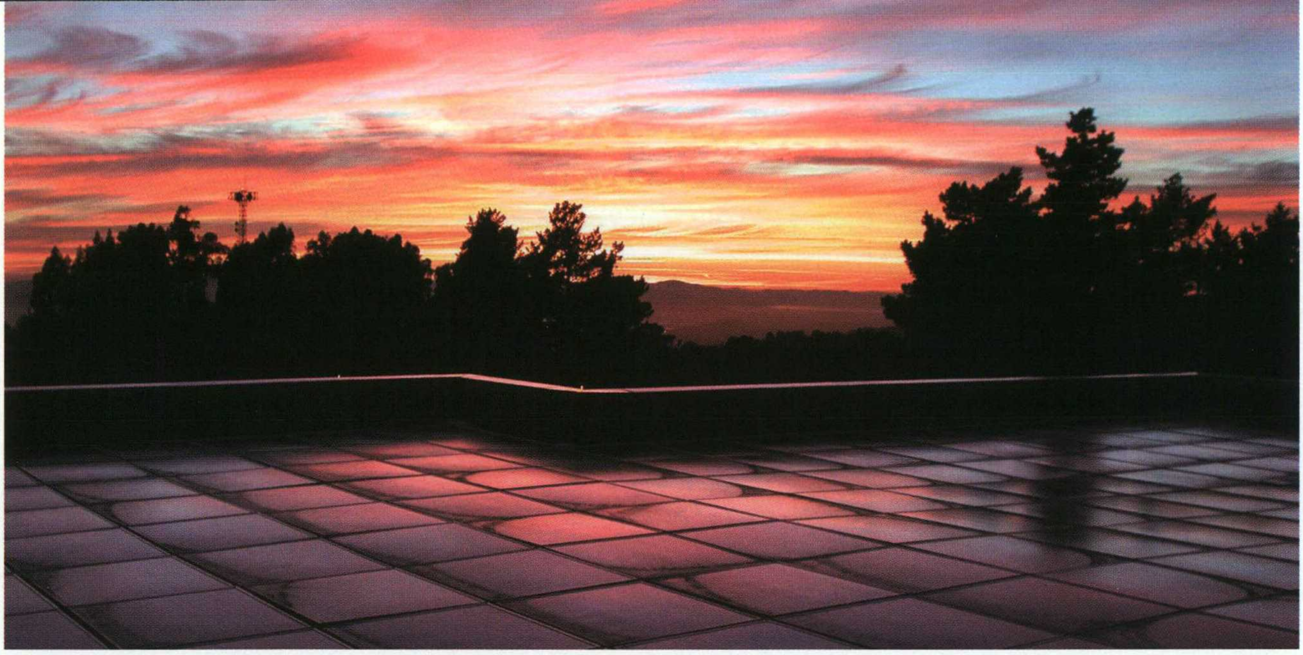
Krzysztof Kaliński

Energy vs. exergy: As water drops over the falls, its potential energy is converted via kinetic energy to thermal energy, but on the whole it is conserved. Still, we can see that something – its ease of use in performing work – is being lost here. This lost quantity is called exergy

Thermo-ecological cost

The depletion of non-renewable natural resources is very dangerous for the future development of humankind. The quality of these resources may be characterized in terms of their exergy. The present author, therefore, introduced the concept of thermo-ecological cost, expressing the cumulative consumption of non-renewable exergy per unit of any product considered useful. This thermo-ecological cost should also take into account the consumption of non-renewable exergy for protecting the environment or for compensating the negative results of deleterious emissions in production processes. How to analyze and minimize the thermo-ecological cost is the basic question addressed by thermo-economic economy. The task of this field is not to replace or supplement classical economics, because it has a quite different objective function. The thermo-ecological cost is expressed not in monetary units but in energy (exergy) units.

The practical impact of the thermo-ecological cost would be considerable if a pro-ecological tax were to be introduced. The American researchers R. Repetto and Dover noticed that the personal income tax charges citizens for the positive effects of their activity (work intensity, creative incentives). They suggested introducing a pro-ecological tax linked to the extent of the pollution resulting from human activities. Such a tax should enhance a more rational use of natural resources and better protection of the environment. However, pollution is not the sole negative effect of human



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The main source of renewable energy is solar radiation. It is worth noting that radiation exchange with very cold cosmic space is also a considerable source of exergy delivered to the Earth

activity. Equally negative is the depletion of non-renewable natural resources, which can be expressed by means of the thermo-ecological cost. A second kind of tax, the value added tax or VAT, depends on the consumption of market products. It is desirable for this consumption to be curbed, because this denotes a decrease in the depletion of natural resources and environmental pollution. However, the rates of VAT that are levied result solely from arbitrary administrative decisions; they do not depend on any objective criterion.

The present author has proposed replacing the two taxes under discussion with a pro-ecological tax proportional to the thermo-ecological cost of a given market product. The coefficient of proportionality should be determined by the government, according to the needs of the state. The structure and payment mode would be similar to that of VAT. Natural raw materials extracted from natural deposits should be burdened with this new tax. Only in this case would it be necessary to calculate the thermo-ecological cost. This would comprise the exergy of the raw material and the components resulting from the extraction process. The market price of every product (extracted raw materials included) should contain the value of the tax paid in previous steps of the production processes. Therefore, every producer should increase the sales price of his products according to the increased purchase prices of the raw materials, energy carriers and equipment used in its production. The sale price increment resulting from the tax contained in the price of the production equipment purchased should be determined using the discount calculus, because the reimbursement of this component of tax may last until the end of the production equipment's lifetime.

In collaboration with A. Ziebik and W. Stanek, the present author has been developing calculations of the thermo-ecological cost and a pro-ecological tax. It has been very interesting to compare the thermo-ecological cost of imported and domestic crude oil and natural gas. The financial means for imports are gained through exports. When the exported products have a small thermo-ecological cost (an effect that appears in the case of agricultural, forest or high-tech products), the thermo-ecological cost of imported fuels can be smaller than that of domestic fuels.

Renewable energy sources are being used more and more often in the production of electricity. However, such "clean" electricity is also burdened with some thermo-ecological cost, because production equipment cannot be fabricated without some consumption of non-renewable resources. Such effects are investigated by means of *life cycle assessment*, which takes into account the consumption of non-renewable exergy in the total time from the origin to the dismantling of the worn-out equipment.

A look into the future

New fields of application for exergy analysis are appearing continuously in the world literature, yet not all of them seem to be rational. For example, applications in social sciences are presumably not reasonable. However, one field may be very interesting for young researchers, namely the analysis of exergy losses in living organisms. For example, the exergetic efficiency of the vegetation of plants is very low. The reasons behind such an effect are worth investigating. In the human body, too, the exergy losses are considerable. In a mature organism, the total exergy of food is transformed into the considerably smaller exergy of waste materials or heat rejected into the environment. The reduction of these losses might be interesting from the point of view of food consumption and human health. ■

Further reading

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